A STUDY OF THE ACOUSTICAL PROPERTIES OF VENTILATION DUCT TERMINAL DEVICES

James Edward Kaune

and

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Monterey, California

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JAMES EDWARD KAUNE, Lieutenant (junior grade), U.S. Navy
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CALVIN EUGENE RAKES, Lieutenant, U.S. Navy
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SUBMITTED IN PARTIAL FULFILLMENT OF THE
REQUIREMENTS FOR THE DEGREE OF
NAVAL ENGINEER

from the
MASSACHUSETTS INSTITUTE OF TECHNOLOGY
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Authors..

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Department of Naval Architecture and Marine Engineering
May 23, 1955

Thesis Supervisor..

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The purpose of this investigation was to present the results of acoustical measurements on six representative types of ventilation duct terminal devices and determine what characteristics or trends, if any, they might have in common. The acoustical measurements to be made consisted of sound pressure levels in one-third octave bands from 50 cps to 10,000 cps as a function of effective velocity and volumetric rate of flow. Directivity patterns were also taken for typical values of air flow to determine whether the terminal devices were directive to any appreciable degree. From the above data acoustic power level could be calculated.

Three grilles, two registers and one diffuser were tested under various configurations of damper position and air throw.

The test set-up consisted of mounting the test specimen in a large heavy measuring duct. Air is supplied by a centrifugal fan which is acoustically isolated from the measuring duct by means of a sinusoidal muffler. To prevent longitudinal standing waves in the duct, it was coupled via an exponential horn to an anechoic termination. The microphone was shielded by a windscreen and was located downstream from the device under test.

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ii

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The test data obtained indicated that the directivity of the device was small. The power level in the region tested increased at a rate of about 18 decibels per octave of air velocity. On the other hand, the PWL_{SIL} increased at about 25 per octave of air velocity. It appears that a good parameter for comparing grilles and registers of the same size is the effective velocity. Since the only size of grille and register tested was 10" x 5" it was impossible to say what the effect of size on the PWL and PWL_{SIL} is; however, Stewart and Drake [12] in their empirical equations for loudness include a term containing core area, from which one would infer that acoustic power is also directly proportional to the core area, effective velocity being held a constant. There is no previous data with which these results could be compared.

Further work is necessary in order to obtain more statistical data on other types of diffusers. Also additional work is necessary to ascertain the effect of varying size on the PWL and PWL_{SIL}.

Thesis Supervisor: Leo L. Beranek
Title: Associate Professor of Communications Engineering

The test data obtained indicated that the directivity of the device was small. The power level in the region tested increased at a rate of about 15 decibels per octave of air velocity. On the other hand, the PWL_{SIL} increased at about 25 per octave of air velocity. It appears that a good parameter for comparing grilles and registers of the same size is the effective velocity. Since the only size of grille and register tested was 10" x 5" it was impossible to say what the effect of size on the PWL and PWL_{SIL} is; however, Stewart and Drake (12) in their empirical equations for loudness include a term containing core area, from which one would infer that acoustic power is also directly proportional to the core area, effective velocity being held a constant. There is no previous data with which these results could be compared.

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TABLE OF CONTENTS

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Until recently the ventilation design engineer had long been handicapped by the lack of adequate data for predicting system noise quantitatively prior to installation and operation of the system. On board ship we find that the primary source of noise outside the machinery space is the ventilation system.

Although considerable effort has been directed along the lines of design of ventilation ducts and plenum chambers for attenuating the noise of the fan, little quantitative investigation of the noise makers themselves had been made.

One of these noise makers, the fan, has recently been investigated and reported in papers before the Acoustical Society. In March 1953, two articles appeared concerning this problem. The first, written by L. L. Beranek, J. L. Reynolds and K. E. Wilson, described the apparatus and procedures for predicting ventilation system noise; the second, by C. F. Peistrup and J. E. Wesler, reported the acoustical measurements taken on five commercially available ventilating fans using the apparatus described in the first paper. In March 1955, a paper by L. L. Beranek, G. W. Kamperman and C. H. Allen was published in The Journal of the Acoustical Society of America on the subject of noise of centrifugal fans. In order to overcome some of the limitations of the previous work, it had covered a larger number of fans over a wider range of horsepower.

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The Material Laboratory at the New York Naval Shipyard has performed work in the field of ventilation system noise and recently the Bureau of Ships, Department of the Navy, has issued a notice, based in part on the findings of the above mentioned laboratory, setting forth a method for determining noise from ventilation and air conditioning systems for ships.

Very little work has been done in a quantitative way regarding a second noise maker, the terminal device. The earliest reference these writers were able to find regarding a work of this kind was "The Noise Characteristics of Air Supply Outlets," by D. J. Stewart and G. F. Drake, published in the 1937 transactions of the American Society of Heating and Ventilating Engineers. This work did not indicate that any attempt was made to obtain spectrum levels, directivity patterns, or sound power level. Only loudness level in a room of 100 sabins was determined as a function of the air face velocity and the grille core area. Only a long throw type of grille was tested.

Certain manufacturers of air supply outlets do publish small scraps of information giving "A" scale loudness level that may be expected for various ranges of volumetric rates of flow; however, it is not adequate for good design purposes.

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straight and diverging throw and partial closing of the dampers was investigated. The acoustical measurements consisted of measuring in one-third octaves the band pressure levels in the measuring duct as a function of volumetric rate of flow and effective velocity where appropriate. From these data the overall sound pressure level and the speech interference level over a 2.4 ft^2 area was calculated.

Directivity patterns in three octave bands were obtained for a typical volumetric rate of flow.

The proposed method for obtaining the data consisted basically of measuring the band pressure levels in a large duct inside of which was mounted the device under test. Air was supplied by a centrifugal fan, acoustically isolated from the rest of the system by a sinusoidal muffler. Standing waves in the measuring duct were prevented by coupling it to an anechoic termination via an exponential horn. Volumetric rate of flow was determined by measuring the air velocity upstream from the grille, register or diffuser under test where the air velocity was reasonably uniform all the way across the duct.

There was a common trend noted between all devices tested which, it is believed, may be of value to the designer. Further investigation is necessary in order to determine the effect of varying grille size on its acoustical properties.

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II APPARATUS AND PROCEDURE

Since the reliability, repeatibility, accuracy and sense of the data obtained is of paramount importance the apparatus and instrumentation used must yield results which are relatively free from the disturbing influences present when the data was obtained. A complete description of the apparatus and instrumentation is , therefore, considered to be necessary.

A. APPARATUS

The main components used were: a controlable speed fan, a sine wave muffler, a measuring duct, adapters, an anechoic duct termination and a plywood baffle. (See Fig. 1).

The measuring duct was 7 feet long and had a circular cross-section with a 21 1/8 inch inside diameter. It was constructed with 1/16 inch galvanized steel and was coated with about 1/4 inches of Komul (a standard vibration damping mastic). Straightening vanes 1 foot in length were inserted at the muffler connecting end of the duct so that the turbulence would be reduced to a minimum. At the terminal end of the duct there was a square exponential horn which led to the anechoic terminator. The resulting effect of the horn and anechoic termination combination was to effectively eliminate longitudinal standing waves.[1] All flanged sections contained soft rubber gaskets which eliminated air leakage and reduced vibration transmission to a minimum.

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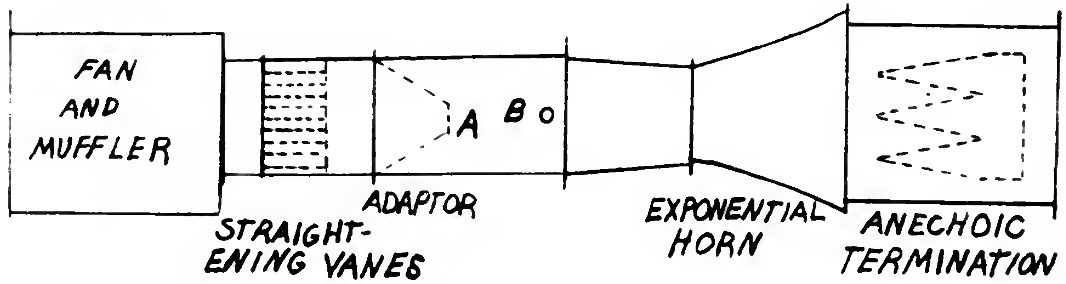

FIGURE I

A. VENTILATION TERMINAL DEVICE
B. MICROPHONE OPENING

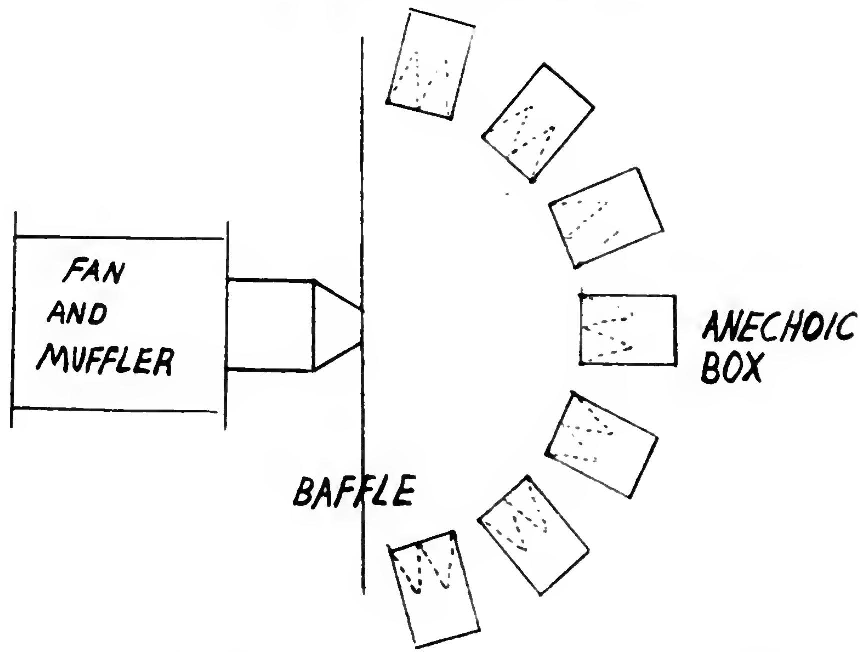

FIGURE II

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Since a reasonable cross-sectional area of duct to area of grille as well as a sufficient range of air velocities through the grille was desired it was necessary to construct tapered conical adapters. Each was 2 feet long with a 21 1/8 inch diameter at one end but one tapered to a round 8 inch diameter terminal ending while the other tapered to a 9 1/2 inch by 4 1/2 inch rectangular terminal ending. This made possible the testing of rectangular as well as round ventilation terminal devices.

In order to check the directivity pattern of the ventilation terminal devices the measuring duct was removed and a baffle erected at the terminating end of the adapters. (See Fig. 2). Free field conditions were simulated by surrounding the baffle by a semicircle of anechoic boxes and by covering the floor with acoustical blanket.

B. INSTRUMENTATION

The instruments used were: a low velocity air meter (thermocouple), a pitot tube, a manometer, an Altec-Lansing 21-BR-200 microphone, an Altec-Lansing power supply unit type P -525-A, a Magnecorder (amplifier) type PT6-J, a GR SPL meter type 51-A (20 kc scale), a 1/3 octave band analyzer, a transistor oscillator calibrator and a windscreen.

Since pitot tube measurements at the low velocities found in this experiment are questionable, it was decided that the use of a thermocouple low velocity meter would give more accurate results. Calibration of the air-meter was achieved by using higher velocities and a standard pitot tube.

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The Altec-Lansing 21-BR-200 microphone not only has an extremely flat response over the range of frequencies tested, 20 to 10,000 cps, but also has a small physical size which makes windscreen design simpler and results in a windscreen of small dimensions. The overall result is that there is very little error in measurement caused by the microphone response and the physical size of the microphone and windscreen combination assures minimum interference of the sound field inside the duct.

The windscreen was 5 inches long and had a diameter of 3 inches. It was constructed with wire mesh having 1/4 inch squares covered by standard parachute nylon. Windscreen self noise and sensitivity response corrections were made where applicable.

The Magnecorder was used as the signal amplifier because of its excellent response characteristics over the range of frequencies tested. It has a flat response from 20 to 40,000 cps which more than covers the range of interest for this investigation.

The one-third octave band filter was introduced into the system before the GR SPL meter so that a maximum number of frequency bands could be analyzed. Since the Telefon filter has sharply defined pass bands, corrections for this instrument are quite easily applied.

The GR SPL meter (20 kc scale) also has an extremely flat response over the range of interest.

The microphone was calibrated to read absolute sound pressure level relative to 0.0002 microbar and this reference level was used throughout this investigation.

It was felt that the accuracy of the readings taken depended entirely upon the accuracy of the reader and not upon the instruments themselves. It is believed that with all corrections applied the accuracy of the instruments should fall within a $\pm$ 1 db range whereas the best estimate of the accuracy of the reader is about $\pm$ 2 db in lower bands to $\pm$ 1 db in the higher bands.

C. PROCEDURE

In order to insure that the data obtained were valid many considerations had to be taken in account. They fell roughly into the following categories: directivity, instrumentation crosschecks, repeatability, and instrumentation corrections.

Directivity pattern calculations not only dictated the microphone location and the number of locations necessary for good data, but also served as a check on the PWL's calculated using the measuring duct apparatus. Since the ventilation terminals tested proved to have reasonably non-directive characteristics at the microphone distances used and since wall effects are noted when microphones are placed relatively close to flat or closed surfaces, it was concluded that a center position location of the microphone would prove to be most satisfactory. The results and PWL checks obtained would tend to substantiate this con-

clusion. All readings in this investigation are, therefore, centerline readings.

The instrumentation used in this investigation was cross-checked with a set-up containing a GR SPL meter type 1551 with its regular GR crystal microphone and the GR octave band analyzer type 1550. A noise generator (white noise) was used as the sound source. When the 21-BR-200 and the crystal microphones were located at approximately the same point the octave band readings correlated to within ± 2 db which was considered to be satisfactory.

Several complete reruns of tests run approximately one month earlier were made and the correlation was within ± 2 db. This would indicate that repeatibility was within reason and should cause no particular concern.

Since self-noise of the windscreen could have an appreciable effect upon the readings taken, self-noise curves of the same type and construction windscreen as that used in this investigation were obtained from Bolt Beranek and Newman, Inc., Acoustical Consultants. They showed that self-noise had a negligible effect on the data taken. However, since the sensitivity of the microphone is reduced because of the presence of the windscreen a correction curve for this effect was made and the appropriate correction was applied to the data recorded.

Since it was the objective of this investigation to see what effects ventilation terminal devices had on terminal openings it was clearly

necessary to obtain the noise of the terminal opening alone with no grille attached. This was done.

III DEFINITION OF SYMBOLS AND QUANTITIES

A few of the symbols used herein may not normally be found in any standard textbook on acoustics. Some are useful only in this particular investigation; others are used by ventilation engineers. For the sake of clarity, all symbols used will be listed giving their meaning, and, where appropriate, their definitions.

A_c = core area of a register or a grille. This is the area of the hole which would result if grating or fins were removed. Usually the core dimensions are one-half inch shorter on each dimension than the nominal grille size. For example, the size used in this investigation was 10" x 5". The core dimensions were therefore 9 1/2" x 4 1/2", giving a core area of 0.297 ft^2.

A_e = effective area of a register or grille. For the grilles and registers with dampers fully open, it was taken to be the core area less the projected area of the grating or fins into the plane of the face of the grille. For the register with partially closed dampers, the effective area was taken as the core area less the projected area of the dampers. The effective area to core area ratio varied from .75 to .82 for straight throw grilles. A value of .62 was obtained for diverging throw.

A_n = neck area of the diffuser.

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A_n = neck area of the diffuser.

PWL = acoustic power level measured in decibels re=10^{-13} watt, i.e., PWL = $10 \log_{10} \frac{W}{10^{-13}}$ where W = acoustical watts radiated by the source.

PWL_c = acoustic power level per unit of core area. re = 10^{-13} watt/ft^2. $PWL_c = PWL - 10 \log_{10} A_c$.

PWL_{SIL} = an "acoustic power level" based on speech interference level criterion. The quantity was determined in this manner: the SIL was determined in the usual manner (see definition of SIL following) at the point in the measuring duct where the microphone was located. To this value was added $10 \log_{10} S$, S being the area of the duct in ft^2 at that point.

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p' = static air pressure in 21" duct upstream from device under test. Pressure is measured in inches of water.

p = pressure drop in inches of water across the device under test. This value was calculated by the following equation:

PWL = acoustic power level measured in decibels re 10^{-13} watt, i.e., PWL = $10 \log_{10} \frac{W}{10^{-13}}$ where W = total acoustic watts emitted by the source.

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$$p = p' - \frac{1}{2} \rho (V_2^{\,2} - V_1^{\,2})\, 0.192$$

where ρ is air density in slugs/ft^3, V_1 is velocity in 21" duct, V_2 is velocity immediately upstream of the device under investigation. Both are measured in ft/sec. The constant 0.192 is for converting pounds per square foot into inches of water. The velocity V_1 was measured by means of a thermocouple type air meter.

Q = volumetric rate of air flow in ft.^{3}/min.

SPL = sound pressure level. re = 0.0002 dyne/cm^2. As used in this report it refers to the measured sound pressure level in one-third octave bands in the measuring duct.

SIL = speech interference level. Although speech interference level is defined as the arithmetic average of the SPL's in the octave bands 600-1200, 1200-2400, and 2400-4800, the computed SIL's in this investigation do not correspond exactly because of the particular one-third octave band filter used. The closest approach that could be made was to use the arithmetic average of the SPL's in octave bands 568-1136, 1136-2272, and 2272-4544. Thus octave band 568-1136 includes one-third octave bands 12, 13 and 14; octave band 1136-2272 includes one-third octave bands 15, 16 and 17; and octave band 2272-4544 includes one-third octave bands 18, 19 and 20. This difference is believed not to be important.

S = cross-sectional area of measuring duct at the microphone position in ft.^{2}.

$$p = [illegible]\ (V_2^2 - V_1^2)\ [illegible]$$

where ρ is air density in [illegible], V_1 is velocity in [illegible] and V_2 is velocity [illegible] investigation. Units are measured in [illegible]. The [illegible] is for converting pounds per square foot [illegible]. The velocity V_1 was measured by means of a [illegible].

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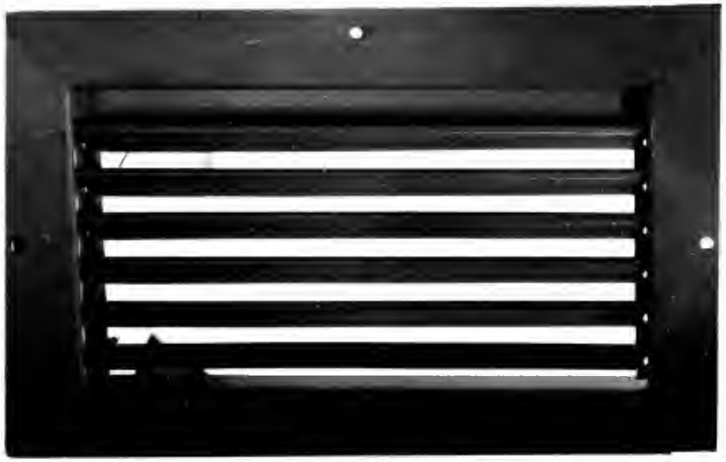
S = cross-sectional area of measuring duct at the microphone position in ft.²

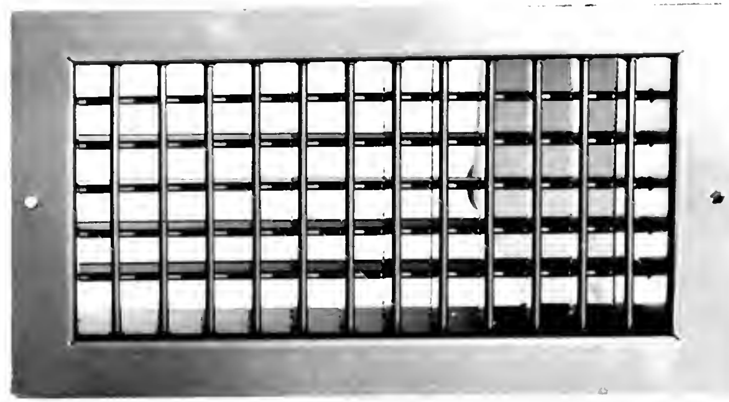
V = effective velocity of air through grille or register. It is defined by the equation:

$$V = Q/A_e$$

V_n = neck velocity in the diffuser.

V_{mike} = local velocity measured at microphone position.





A B

C D

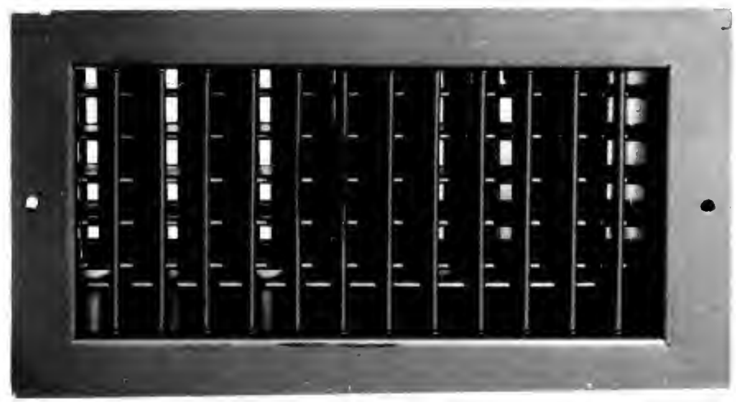
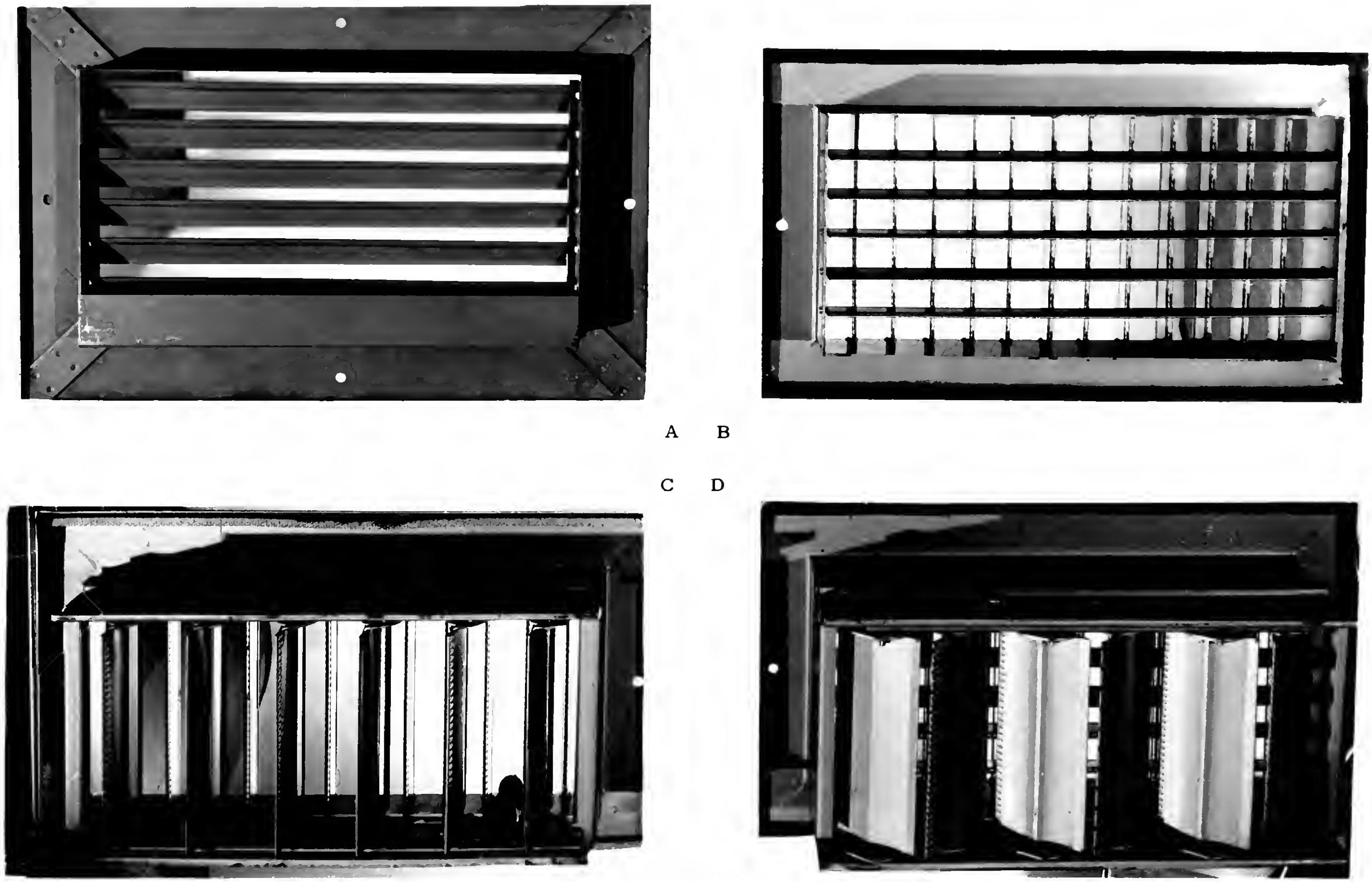


PLATE I
FRONT SIDE

A-DO C-DOV
B-DV D-TROV



A B

C D

PLATE II
BACK SIDE

A-DO C-DOV
B-DV D-TROV

PLATE III
BAFFLE AND SIMULATED
FREE FIELD SYSTEM

IV CONFIGURATIONS TESTED

Three grilles,* two registers* and one diffuser** were tested. (See Plates I through III.) The grille designated type 188 was stamped from 14 gauge material with 13/16" square hole with 3/16" frets. It is a straight throw type grille. Grille type DO has horizontal fixed face fins set at an angle of 45°. Type DV is a double deflection, double band type grille. The face fins are vertical, the rear fins are horizontal and can be adjusted for either straight or diverging throw. It was tested in both the straight and diverging throw positions.

Type TROV register is the same as grille type DV in so far as fins are concerned. The only difference is in the addition of dampers. Register type DOV is single deflection with vertical face fins which are adjustable to give straight or diverging throw. Type TROV was tested in the straight and diverging throw positions for two damper positions, one position being full open and the other in such a position to give an effective area to core area ratio of 1/2 as defined in Chapter III. The same configurations were tested on the DOV except that a value of 1/3 was selected instead of 1/2 for the effective area to core area ratio. Thus a total of four configurations was tested for each register.

The diffuser tested is an adjustable air supply outlet consisting of four cones. The inner three cones are attached to the outer cone by

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*For registers and diffusers, see General Register Catalog No. 101A, 1954.

**See Anemostat Selection Manual No. 50, 1955, diffuser type C-23.

IV CONFIGURATIONS TESTED

Three grilles,* two registers* and one diffuser** were tested. (See Plates I through III.) The grille designated type 188 was stamped from 14 gauge material with 13/16" square hole with 3/16" frets. It is a straight throw type grille. Grille type DO has horizontal fixed face fins set at an angle of 45°. Type DV is a double deflection, double band type grille. The face fins are vertical, the rear fins are horizontal and can be adjusted for either straight or diverging throw. It was tested in both the straight and diverging throw positions.

Type TROV register is the same as grille type DV in so far as fins are concerned. The only difference is in the addition of dampers. Register type DOV is single deflection with vertical face fins which are adjustable to give straight or diverging throw. Type TROV was tested in the straight and diverging throw positions for two damper positions, one position being full open and the other in such a position to give an effective area to core area ratio of 1/2 as defined in Chapter III. The same configurations were tested on the DOV except that a value of 1/3 was selected instead of 1/2 for the effective area to core area ratio. Thus a total of four configurations was tested for each register.

The diffuser tested is an adjustable air supply outlet consisting of four cones. The inner three cones are attached to the outer cone by

*For registers and diffusers, see General Register Catalog No. 101A, 1954.

**See Anemostat Selection Manual No. 50, 1955, diffuser type C-2A.

means of a central bridge. By rotating the innermost cone the air distribution can be varied from a horizontal pattern to a direct downward discharge. Two configurations were tested, one with the cones set for the horizontal air pattern and the other for the direct downward discharge.

means of a central bridge. By rotating the innercone the air distribution can be varied from a horizontal pattern to a direct downward discharge. Two configurations were tested, one with the cones set for the horizontal air pattern and the other for the direct downward discharge.

V RESULTS

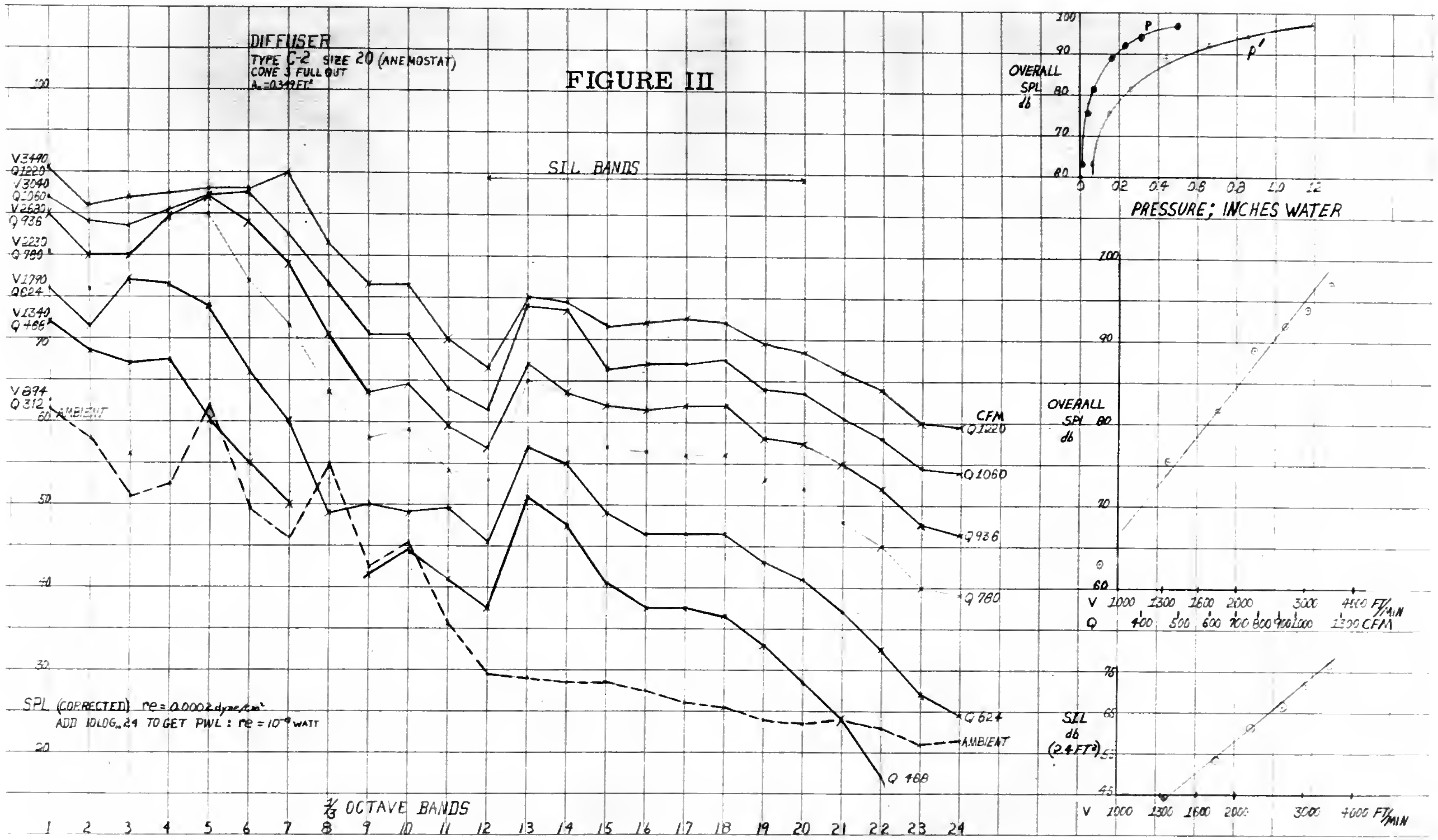
The results of this investigation are embodied in Figures III through XXXVII. The center band frequencies of the one-third octave band filter are given in Appendix B.

Note 1: Data supplied through the courtesy of Bolt Beranek and Newman, Inc., 16 Eliot Street, Cambridge, Mass. See Fig. A-1 of the Appendix.

V RESULTS

The results of this investigation are embodied in Figures III through XXXVII. The center band frequencies of the one-third octave band filter are given in Appendix B.

Note 1: Data supplied through the courtesy of Bolt Beranek and Newman, Inc., 16 Eliot Street, Cambridge, Mass. See Fig. A-1 of the Appendix.



DIFFUSER
TYPE C-2 SIZE 20 (ANEMOSTAT)
CONE 3 FULL OUT
A₀ = 0.349 FT²
SIL BANDS
V3490 Q1220
V3040 Q1060
V2680 Q936
V2230 Q780
V1790 Q624
V1340 Q468
V894 Q312
AMBIENT
CFM
Q1220
Q1060
Q936
Q780
Q624
AMBIENT
Q468
SPL (CORRECTED) re = 0.0002 dyne/cm²
ADD 10LOG₁₀24 TO GET PWL : re = 10⁻¹³ WATT
1/3 OCTAVE BANDS
OVERALL SPL db
PRESSURE; INCHES WATER
P
P'
V 1000 1300 1600 2000 3000 4000 FT/MIN
Q 400 500 600 700 800 900 1000 1300 CFM
SIL db (2.4 FT²)
V 1000 1300 1600 2000 3000 4000 FT/MIN

FIGURE III

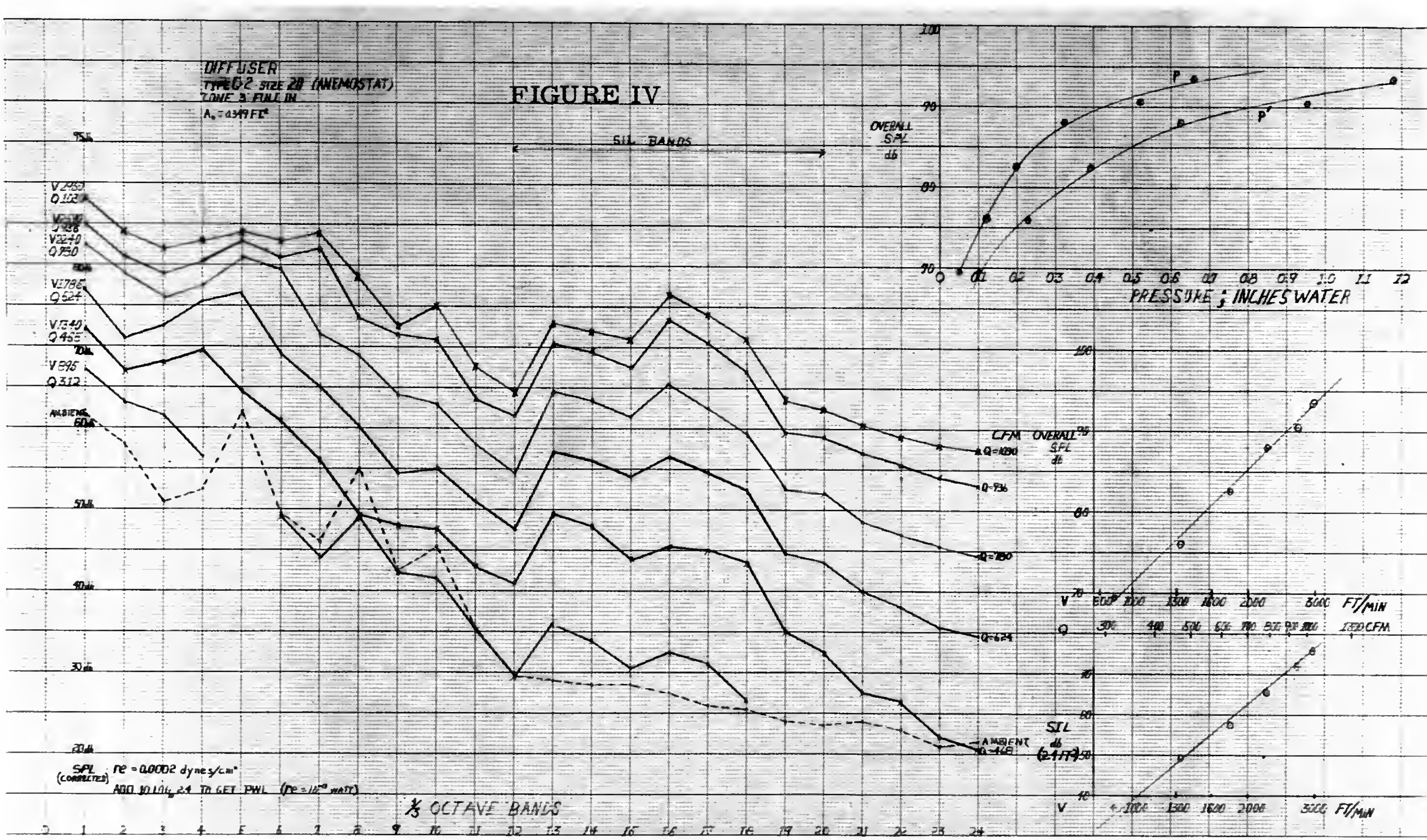


FIGURE IV
DIFFUSER
TYPE C-2 SIZE 28 (ANEMOSTAT)
CONE 3 FULL IN
SIL BANDS
OVERALL SPL db
PRESSURE ; INCHES WATER
CFM OVERALL SPL db
FT/MIN
CFM
SIL db
AMBIENT
SPL (CORRECTED) re = 0.0002 dynes/cm²
1/3 OCTAVE BANDS

FIGURE V

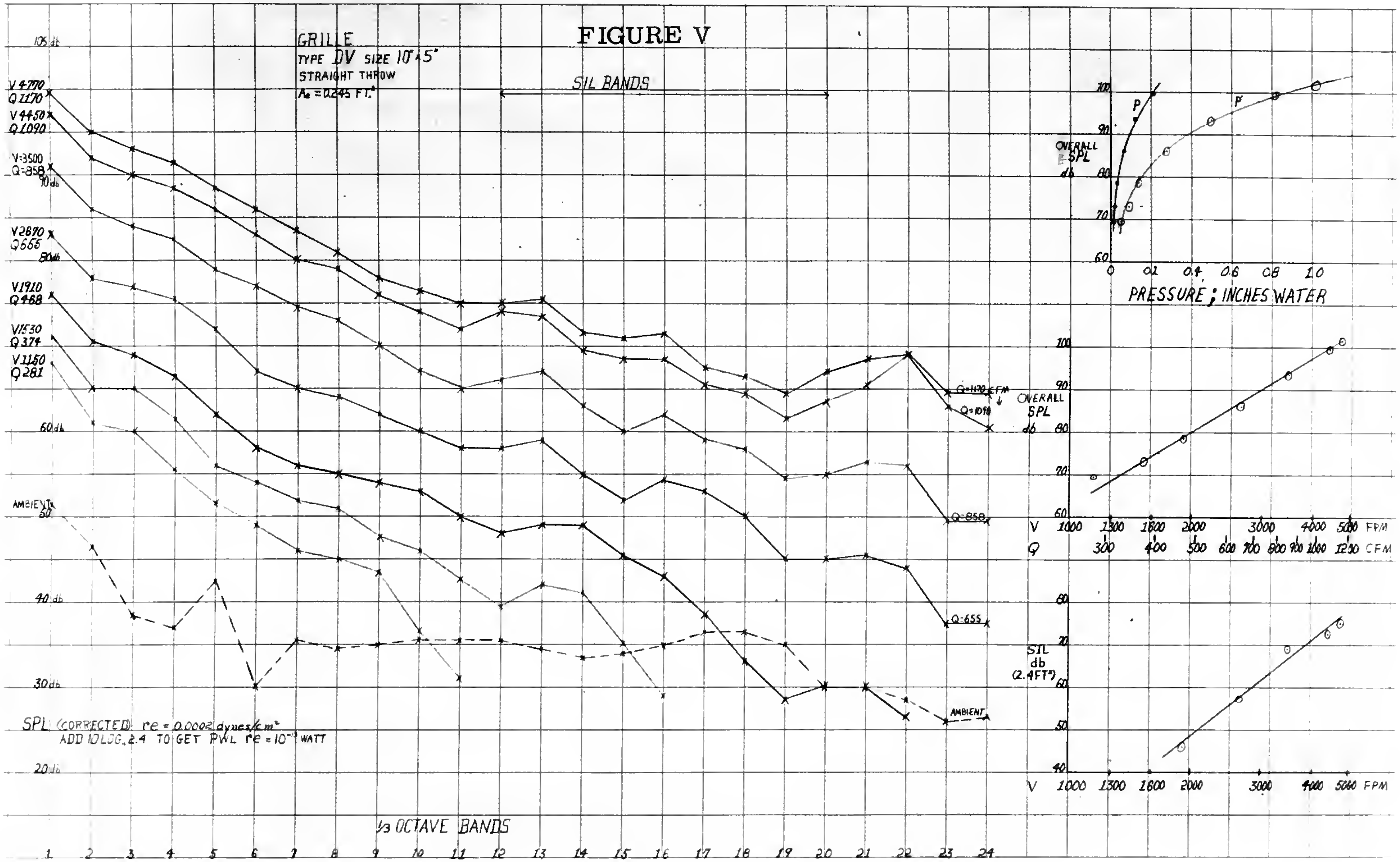
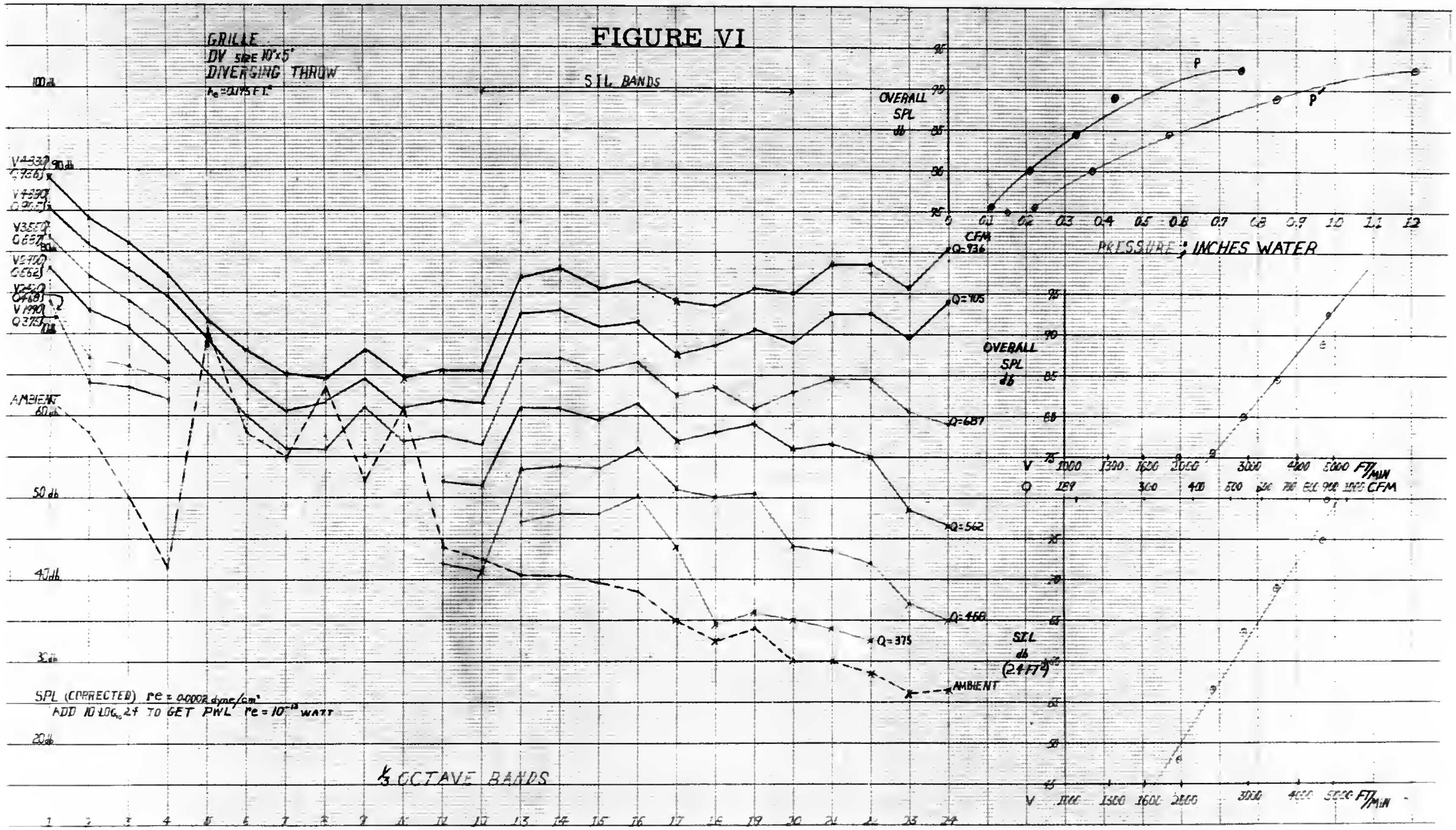

GRILLE
TYPE DV SIZE 10" x 5"
STRAIGHT THROW
A_o = 0.245 FT.²
SIL BANDS
V 4770 Q 1170
V 4450 Q 1090
V=3500 Q=858
V 2870 Q 665
V 1910 Q 468
V 1530 Q 374
V 1150 Q 281
AMBIENT
105 db
90 db
80 db
60 db
40 db
30 db
20 db
Q=1170 CFM
Q=1090
Q=858
Q=655
AMBIENT
SPL (CORRECTED) re = 0.0002 dynes/cm²
ADD 10 LOG 2.4 TO GET PWL re = 10⁻¹³ WATT
1/3 OCTAVE BANDS
OVERALL SPL db
P
P'
PRESSURE; INCHES WATER
V 1000 1300 1600 2000 3000 4000 5000 FPM
Q 300 400 500 600 700 800 900 1000 1250 CFM
SIL db (2.4FT²)
V 1000 1300 1600 2000 3000 4000 5000 FPM

FIGURE VI



GRILLE
DV SIZE 10"x5"
DIVERGING THROW
SIL BANDS
OVERALL SPL db
PRESSURE; INCHES WATER
AMBIENT
Q=736
Q=705
Q=687
Q=562
Q=468
Q=375
SIL db
SPL (CORRECTED) re = 0.0002 dyne/cm²
ADD 10 LOG₁₀ 24 TO GET PWL re = 10⁻¹³ WATT
⅓ OCTAVE BANDS
FT/MIN
CFM

FIGURE VII

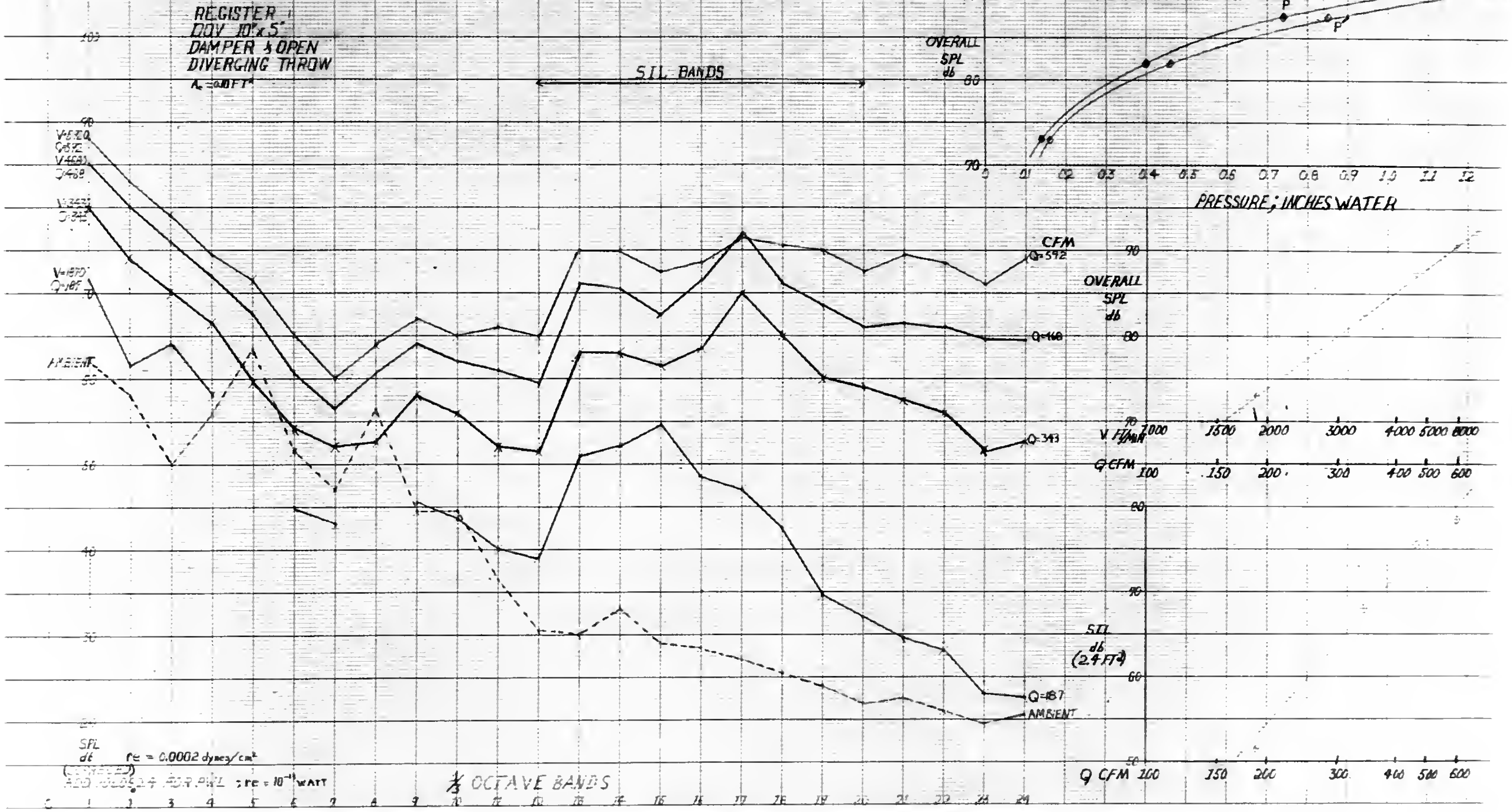

REGISTER
DDV 10"x 5"
DAMPER ½ OPEN
DIVERGING THROW
SIL BANDS
OVERALL SPL db
PRESSURE; INCHES WATER
CFM Q=542
Q=468
Q=343
Q=187
AMBIENT
V FT/MIN
Q CFM
SIL db (2.4 FT²)
SPL db
re = 0.0002 dynes/cm²
⅓ OCTAVE BANDS

FIGURE VIII

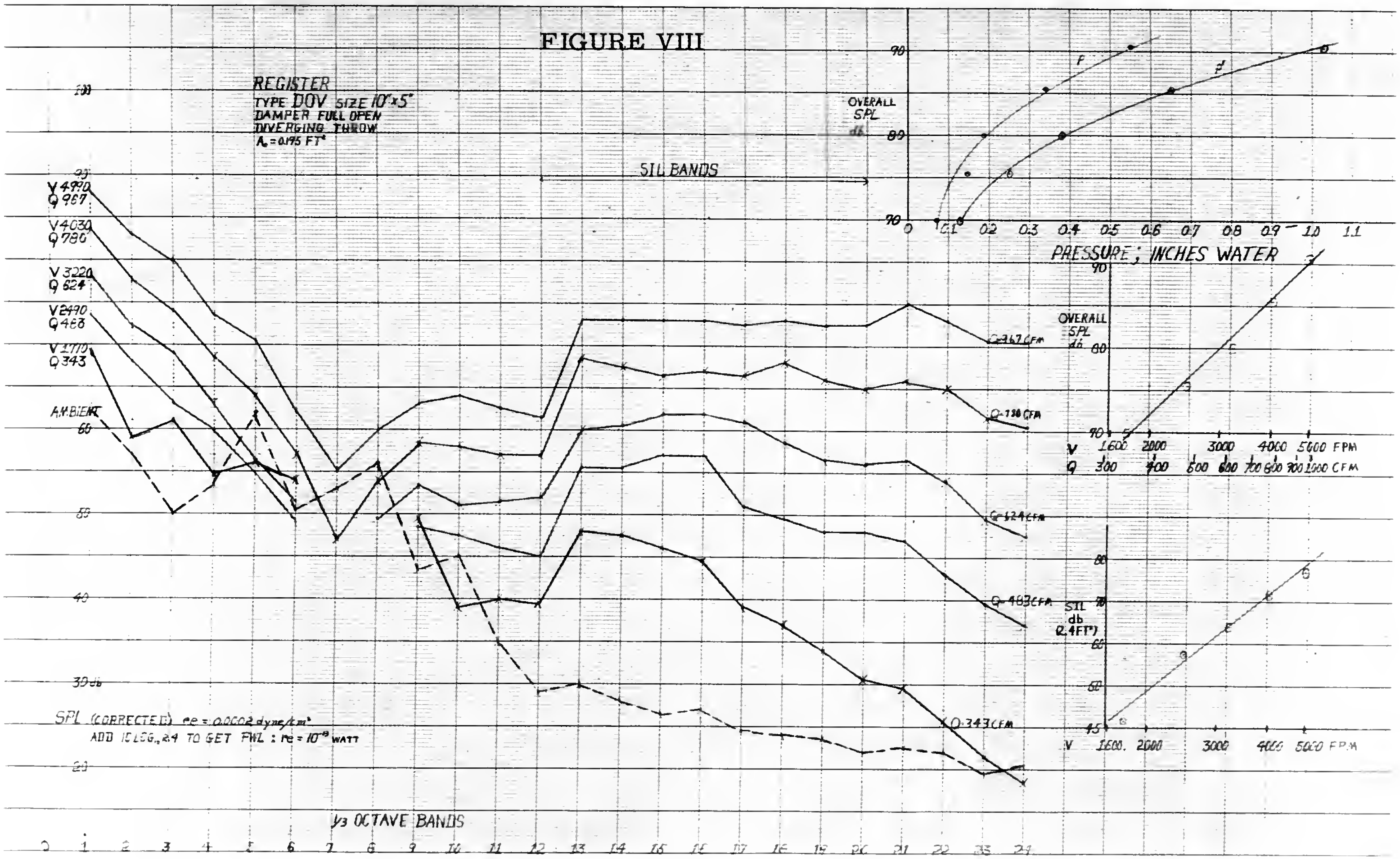
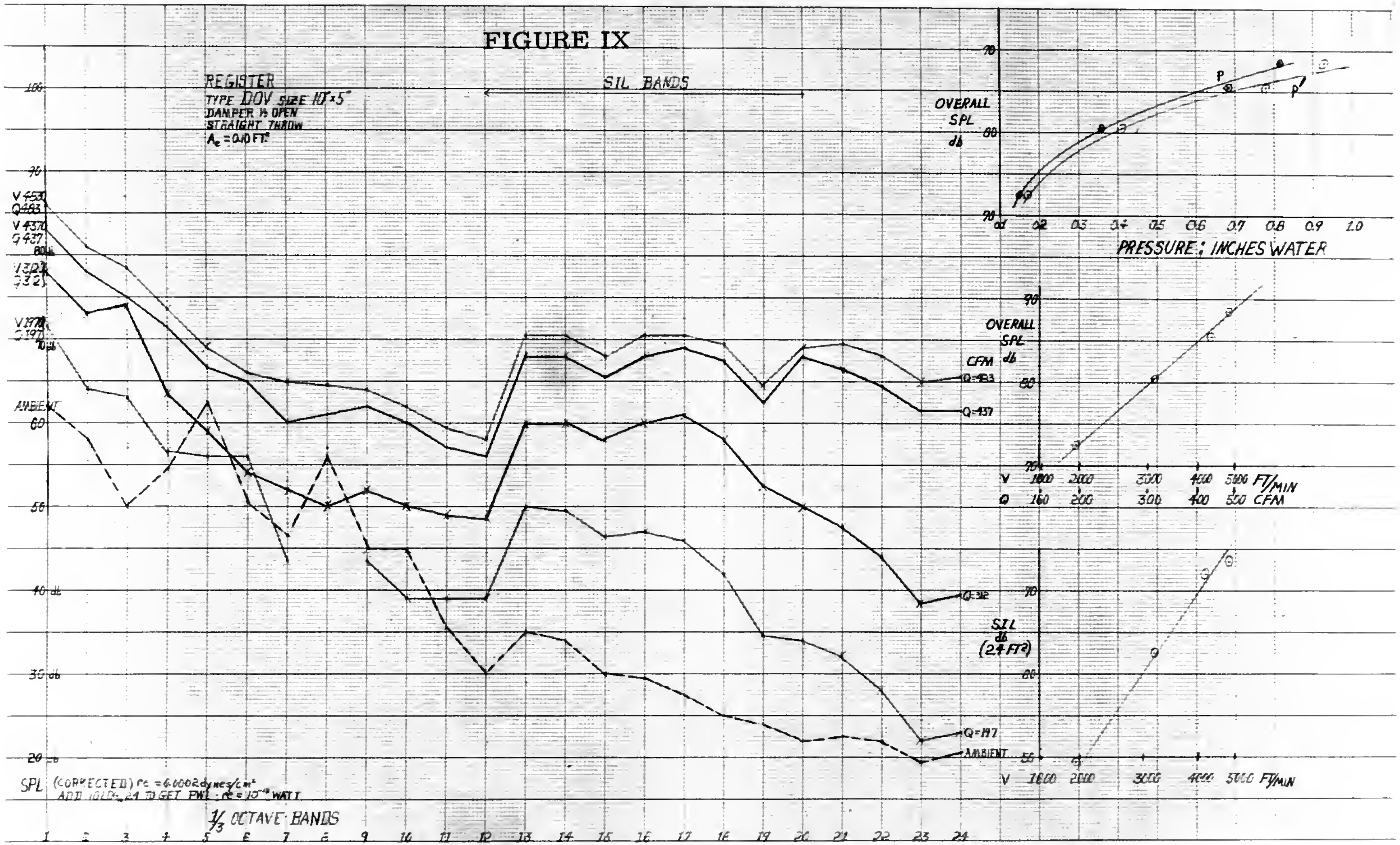

REGISTER
TYPE DOV SIZE 10"x5"
DAMPER FULL OPEN
DIVERGING THROW
A_o = 0.195 FT²
SIL BANDS
OVERALL SPL db
PRESSURE ; INCHES WATER
V 4990 Q 967
V 4030 Q 780
V 3220 Q 624
V 2490 Q 488
V 1770 Q 343
AMBIENT
Q-967 CFM
Q-780 CFM
Q-624 CFM
Q-483 CFM
Q-343 CFM
V 1600 2000 3000 4000 5000 FPM
Q 300 400 500 600 700 800 900 1000 CFM
SIL db (2.4FT²)
V 1600. 2000 3000 4000 5000 FPM
SPL (CORRECTED) re = 0.0002 dyne/cm²
ADD 10 LOG₁₀ 2.4 TO GET PWL : re = 10⁻¹³ WATT
1/3 OCTAVE BANDS

FIGURE IX



REGISTER
TYPE DOV SIZE 10"x5"
DAMPER ½ OPEN
STRAIGHT THROW
SIL BANDS
OVERALL SPL db
PRESSURE: INCHES WATER
OVERALL SPL db
CFM
Q=483
Q=437
Q=312
Q=197
AMBIENT
V FT/MIN
Q CFM
SIL db (2.4 FT²)
SPL (CORRECTED)
1/3 OCTAVE BANDS

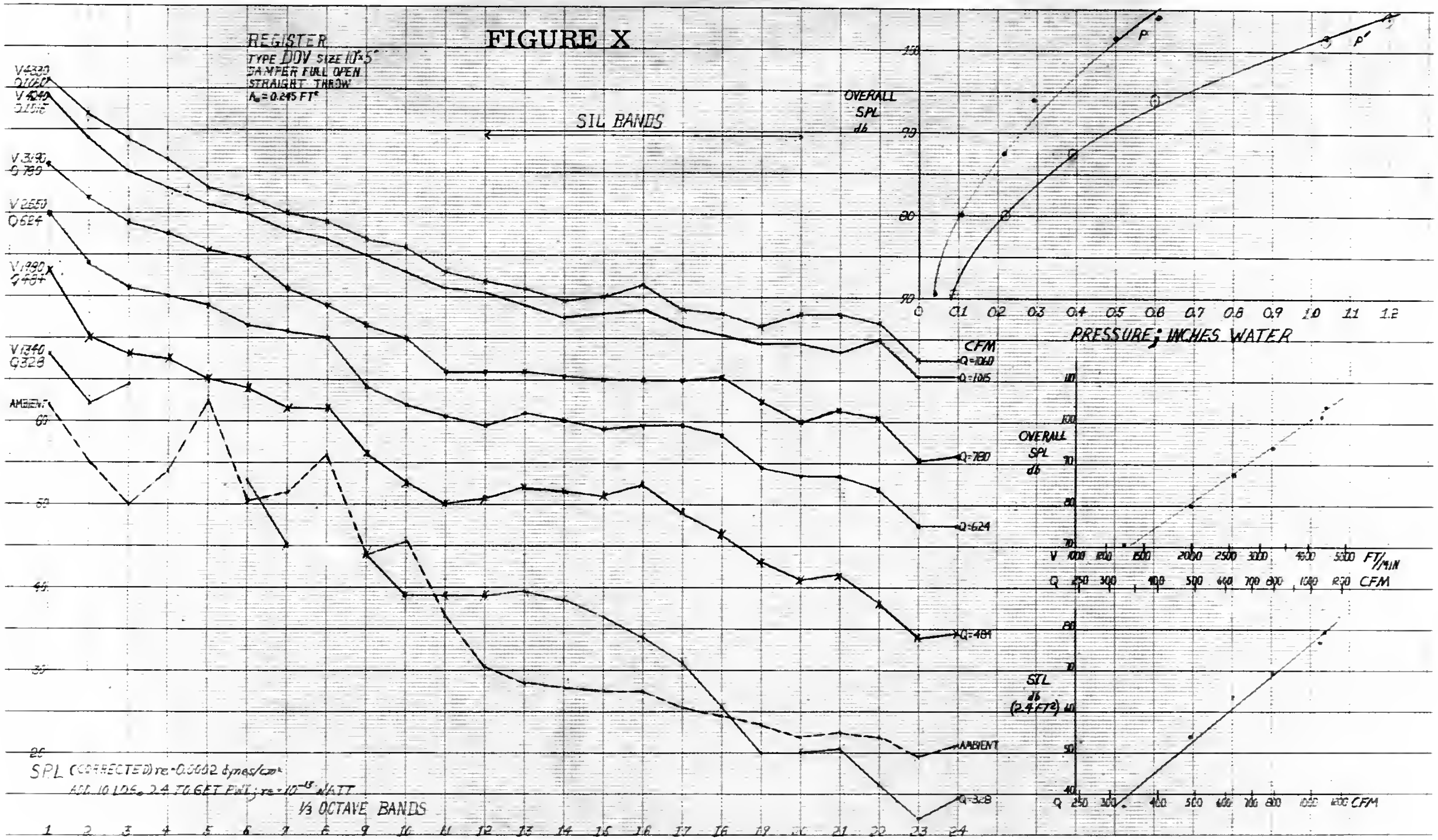


FIGURE X
REGISTER
TYPE DDV SIZE 10"x5"
DAMPER FULL OPEN
STRAIGHT THROW
SIL BANDS
OVERALL SPL db
PRESSURE; INCHES WATER
CFM
Q=1060
Q=780
Q=624
Q=484
Q=328
AMBIENT
V 3190 Q 780
V 2550 Q 624
V 1340 Q 328
FT/MIN
CFM
SIL db
1/3 OCTAVE BANDS

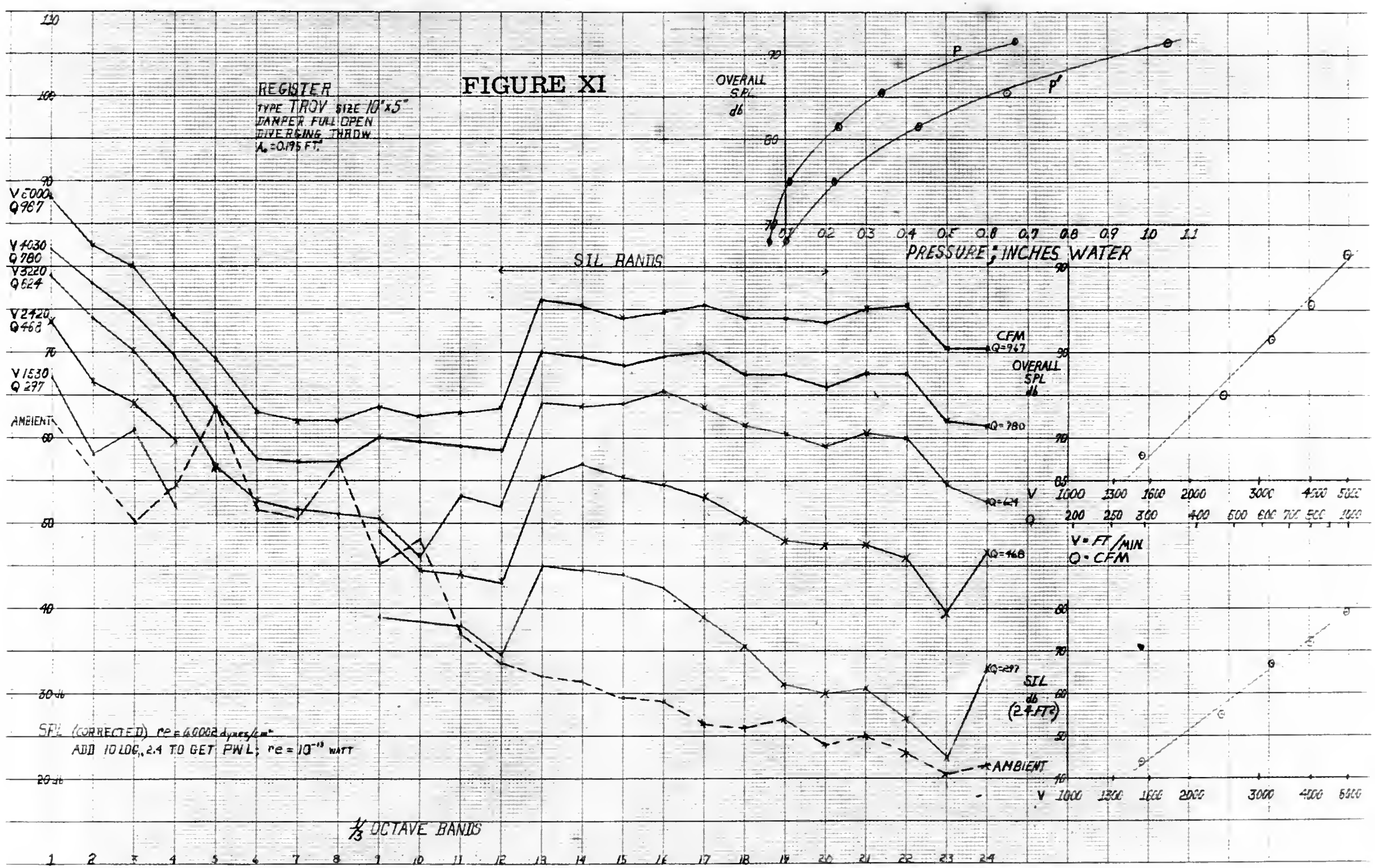


FIGURE XI
REGISTER
TYPE TROV SIZE 10"x5"
DAMPER FULL OPEN
DIVERGING THROW
SIL BANDS
PRESSURE, INCHES WATER
OVERALL SPL db
CFM
OVERALL SPL db
V = FT/MIN
Q = CFM
SIL db
AMBIENT
1/3 OCTAVE BANDS
ADD 10 LOG 2.4 TO GET PWL; re = 10^-13 WATT

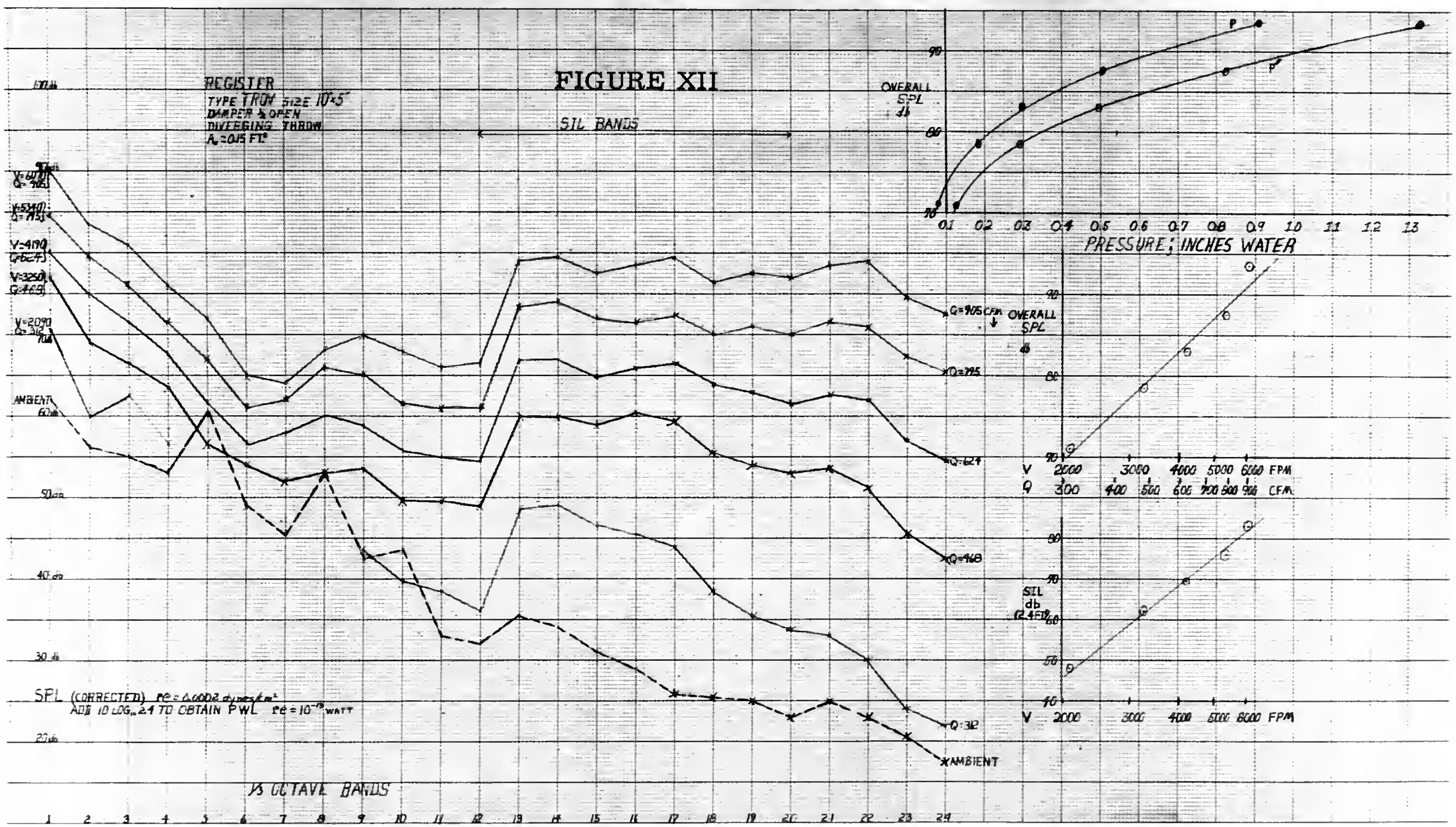

REGISTER
TYPE TROY SIZE 10"×5"
DAMPER ½ OPEN
DIVERGING THROW
SIL BANDS
OVERALL SPL db
PRESSURE, INCHES WATER
Q=905 CFM
Q=795
Q=624
Q=468
Q=312
AMBIENT
V 2000 3000 4000 5000 6000 FPM
V 2000 3000 4000 5000 6000 FPM
CFM
SIL db
SPL (CORRECTED)
ADD 10 LOG 2.4 TO OBTAIN PWL
⅓ OCTAVE BANDS

FIGURE XII

FIGURE XIII

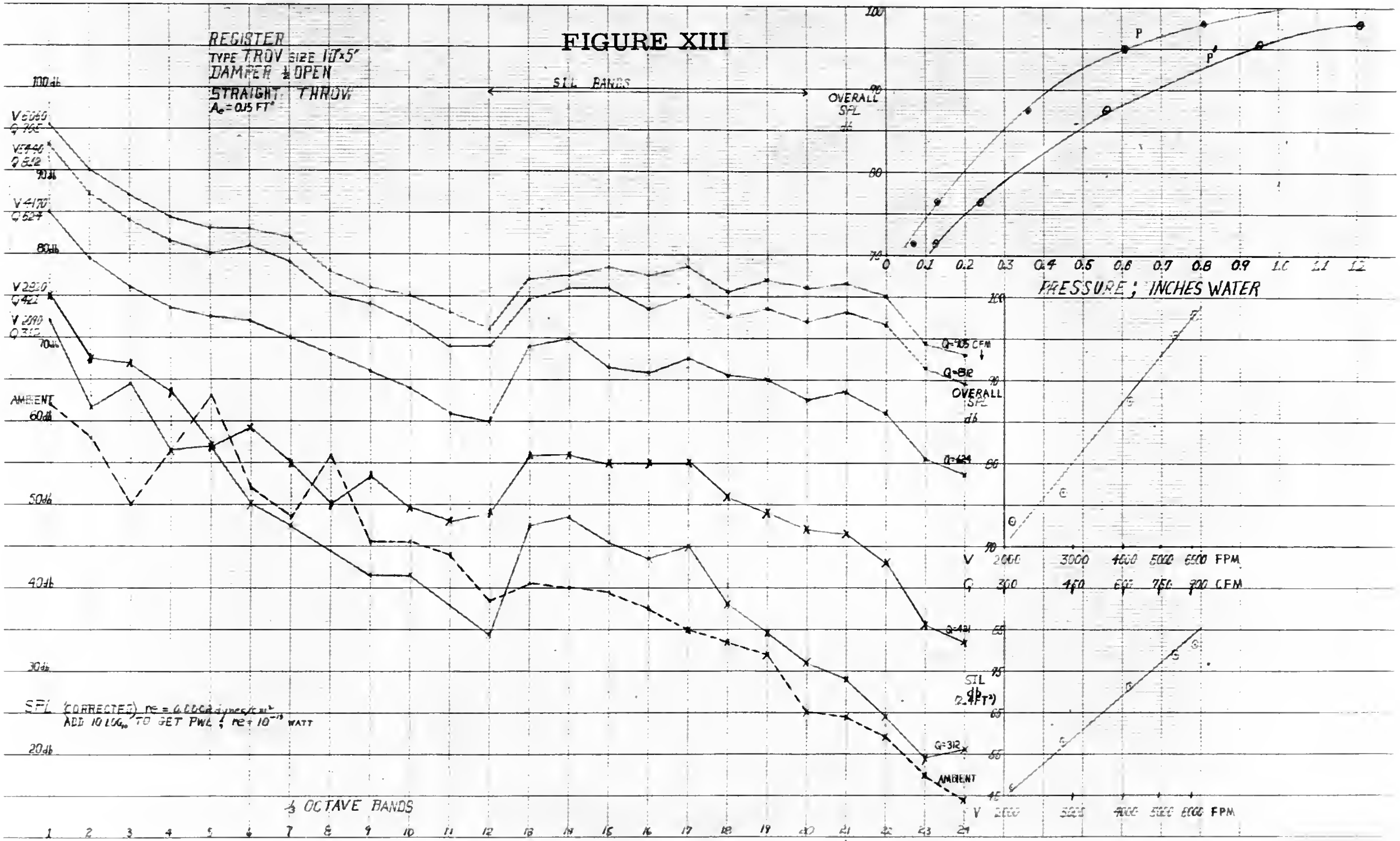

REGISTER
TYPE TROV SIZE 10"x5"
DAMPER ½ OPEN
STRAIGHT THROW
SIL BANDS
OVERALL SPL
PRESSURE ; INCHES WATER
⅓ OCTAVE BANDS
AMBIENT
FPM
CFM

FIGURE XIV

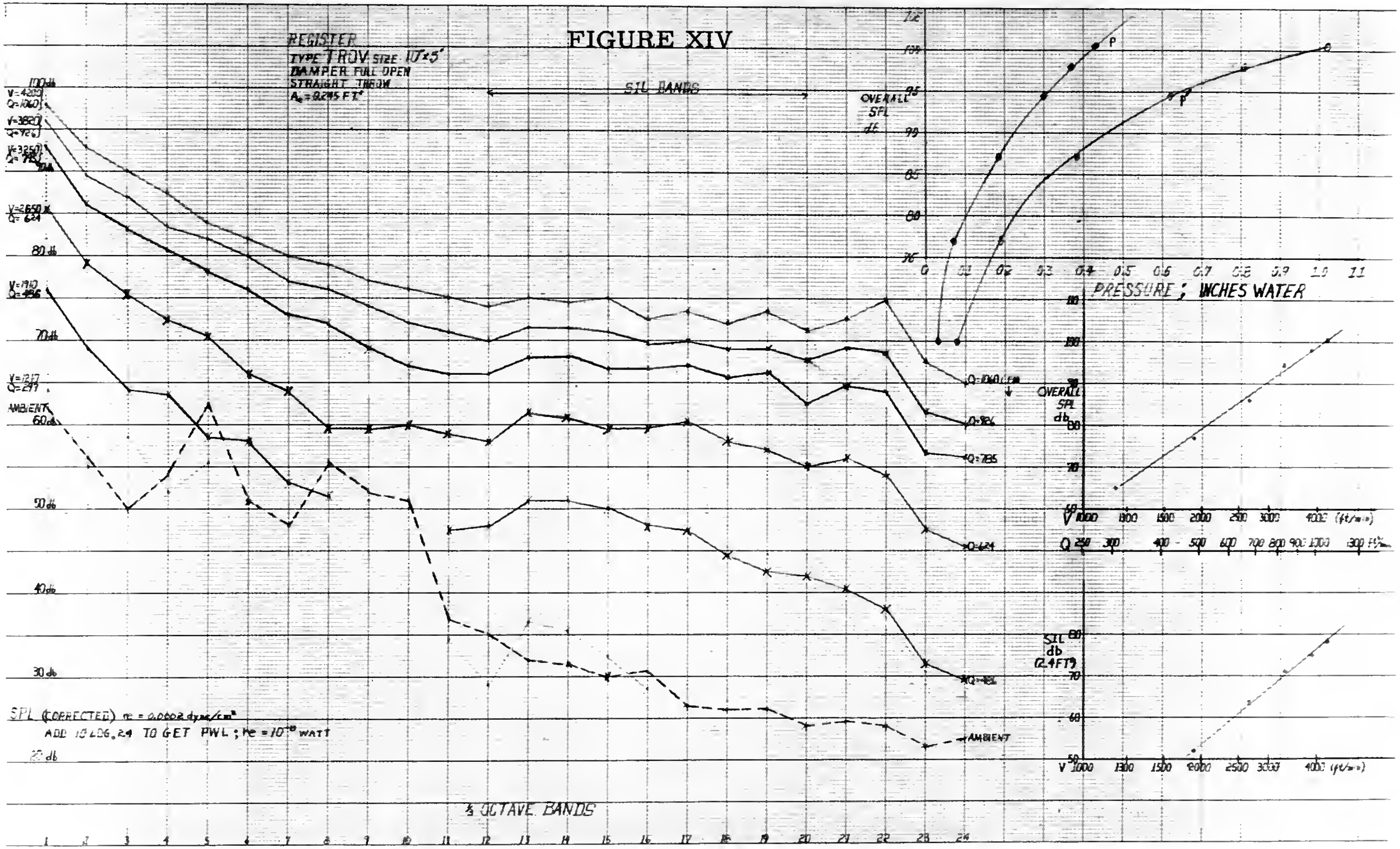

REGISTER
TYPE TROV SIZE 17×5
DAMPER FULL OPEN
STRAIGHT THROW
SIL BANDS
OVERALL SPL db
PRESSURE ; INCHES WATER
SIL db (2.4FT)
AMBIENT
SPL (CORRECTED)
ADD 10 LOG 24 TO GET PWL
⅓ OCTAVE BANDS

FIGURE XV

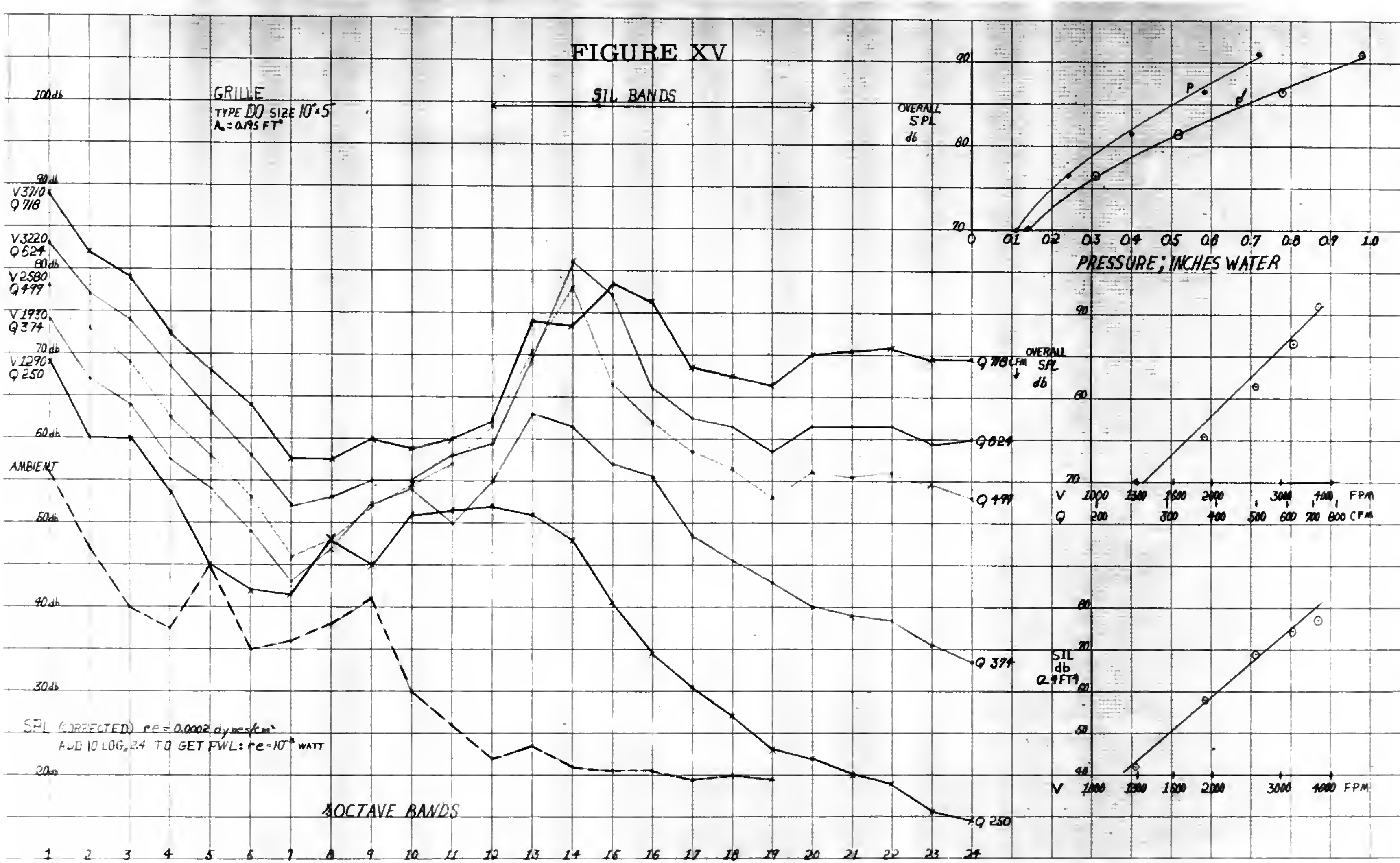
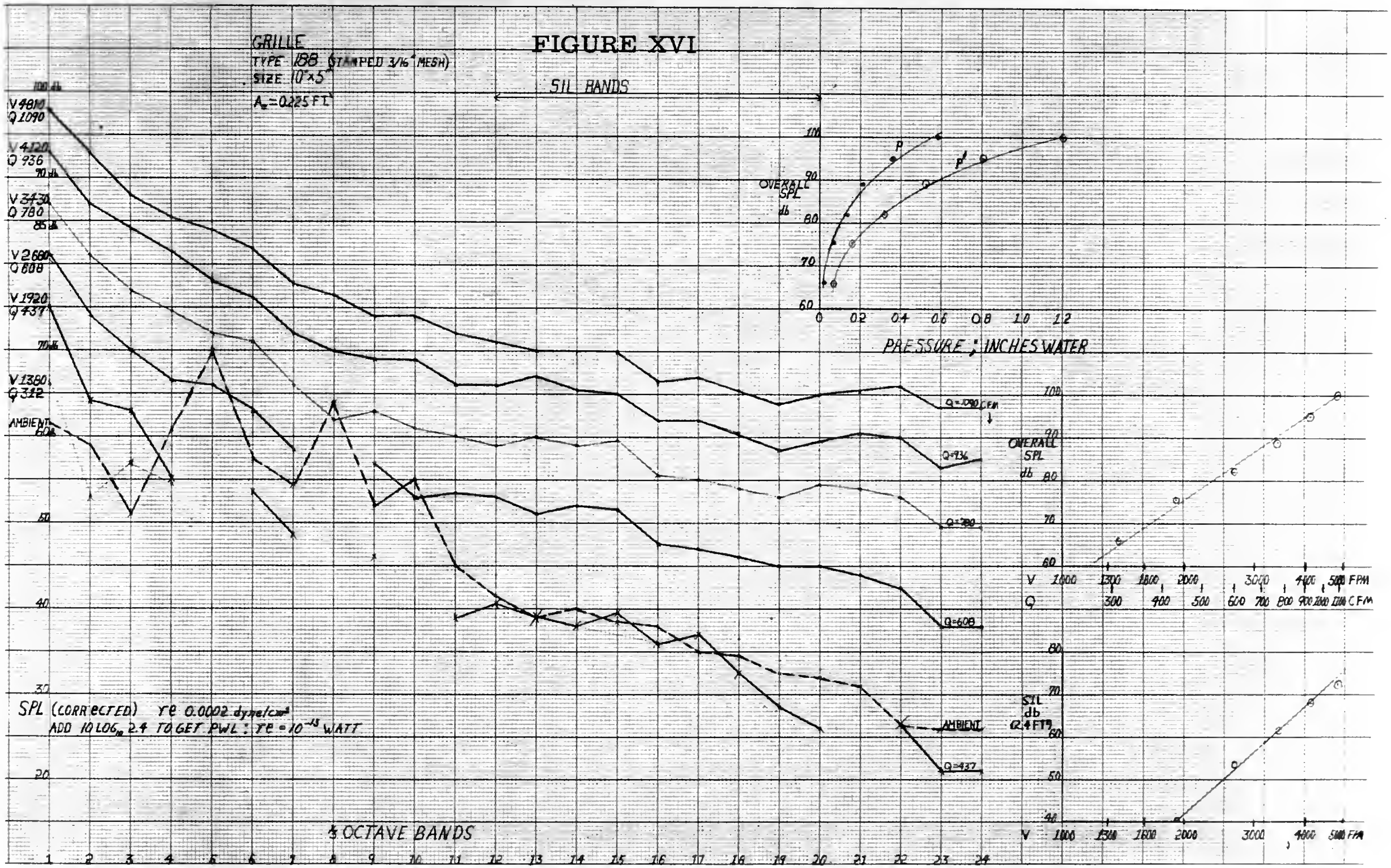
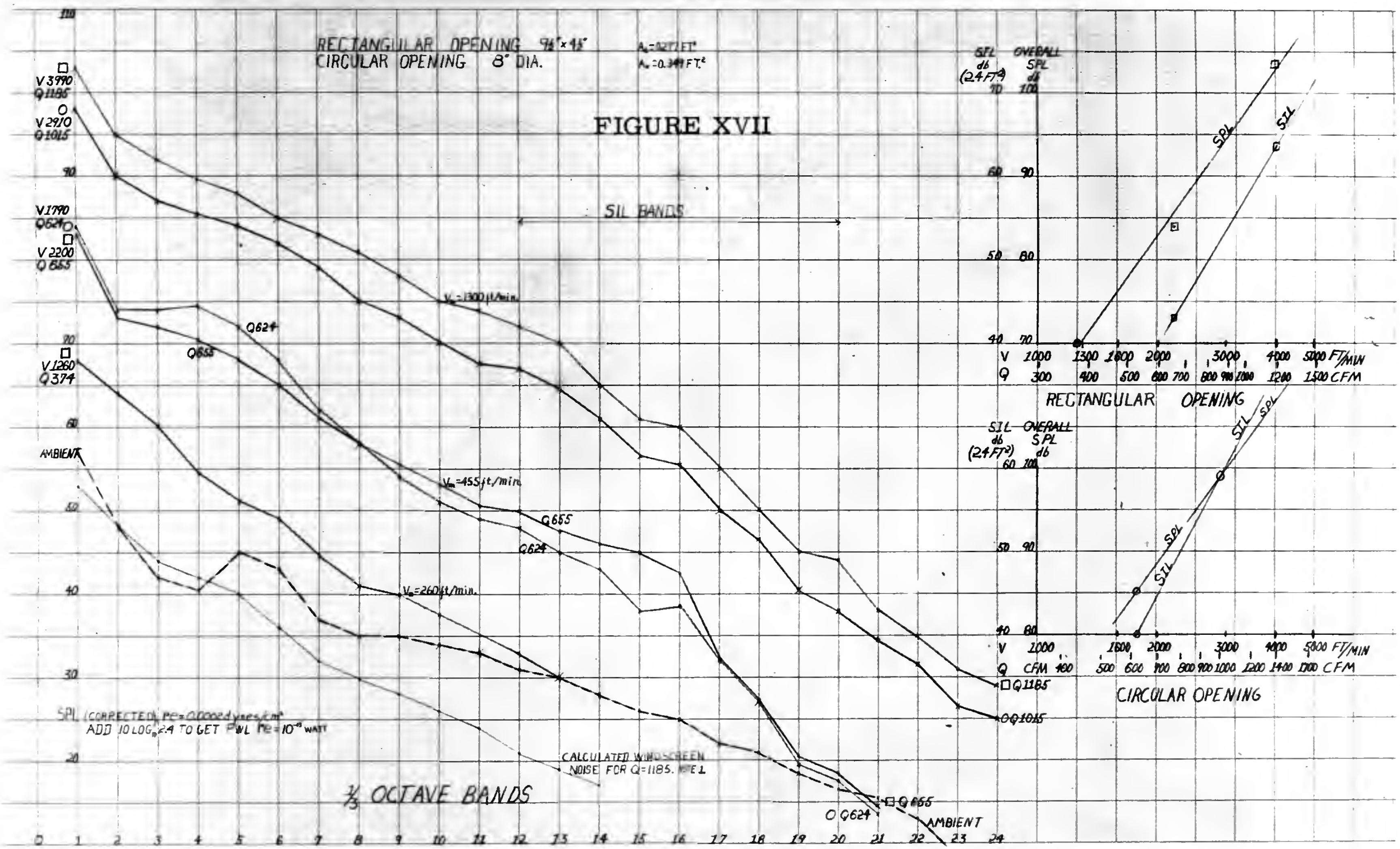

GRILLE
TYPE DO SIZE 10"x5"
SIL BANDS
OVERALL SPL db
PRESSURE; INCHES WATER
V3710 Q718
V3220 Q624
V2580 Q499
V1930 Q374
V1290 Q250
AMBIENT
SIL db
V FPM
Q CFM
SPL (CORRECTED) re=0.0002 dynes/cm²
ADD 10 LOG 24 TO GET PWL: re=10⁻¹³ WATT
OCTAVE BANDS

FIGURE XVI

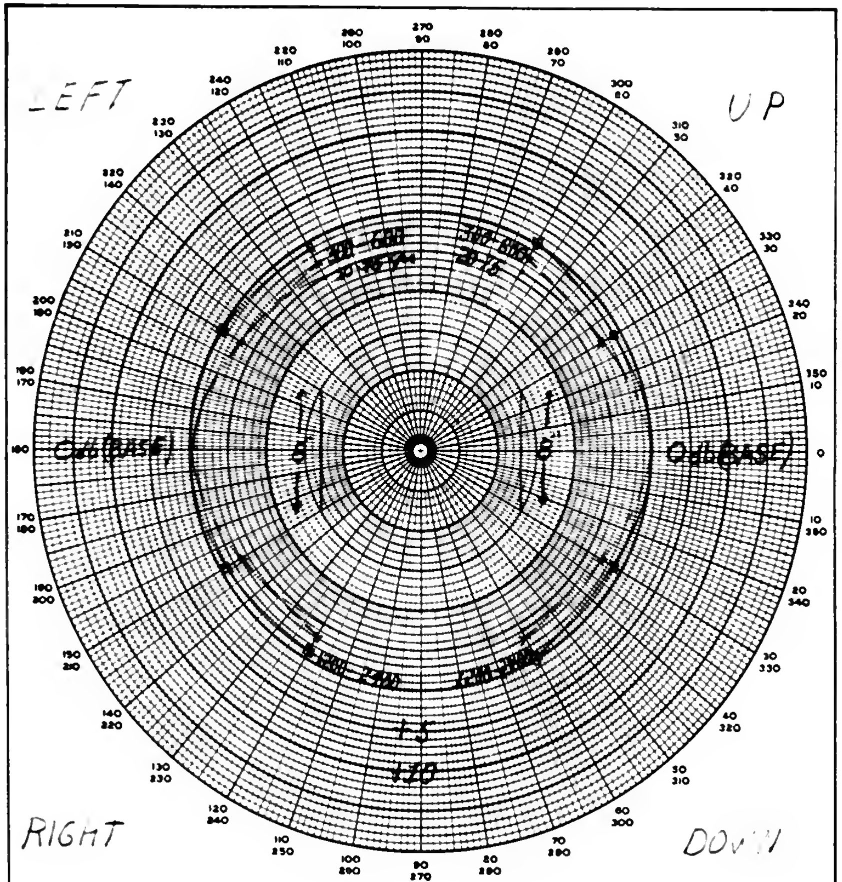


GRILLE
TYPE 188 (STAMPED 3/16" MESH)
SIZE 10"×5"
A_e = 0.225 FT²
SIL BANDS
V 4810 Q 1090
V 4120 Q 936
V 3430 Q 780
V 2680 Q 608
V 1920 Q 437
V 1360 Q 312
AMBIENT
OVERALL SPL db
PRESSURE ; INCHES WATER
Q=1090 CFM
Q=936
Q=780
Q=608
Q=437
AMBIENT
SIL db (2.4 FT²)
V 1000 1300 1600 2000 3000 4000 5000 FPM
Q 300 400 500 600 700 800 900 1000 1100 CFM
SPL (CORRECTED) re 0.0002 dyne/cm²
ADD 10 LOG₁₀ 2.4 TO GET PWL : re = 10⁻¹³ WATT
⅓ OCTAVE BANDS



RECTANGULAR OPENING 9½" x 4½"
CIRCULAR OPENING 8" DIA.
SIL BANDS
V 3990 Q 1185
V 2910 Q 1015
V 1790 Q 624
V 2200 Q 655
V 1260 Q 374
AMBIENT
V = 1300 ft/min.
V = 455 ft/min.
V = 260 ft/min.
Q 624
Q 655
SPL (CORRECTED) Pe = 0.0002 dynes/cm²
ADD 10 LOG 2.4 TO GET PWL Pe = 10⁻¹³ WATT
CALCULATED WINDSCREEN NOISE FOR Q = 1185
⅓ OCTAVE BANDS
SIL db (24 FT²)
OVERALL SPL db
SPL
SIL
V 1000 1300 1600 2000 3000 4000 5000 FT/MIN
Q 300 400 500 600 700 800 900 1000 1200 1500 CFM
RECTANGULAR OPENING
V 1000 1600 2000 3000 4000 5000 FT/MIN
Q CFM 400 500 600 700 800 900 1000 1200 1400 1700 CFM
CIRCULAR OPENING

FIGURE XVII

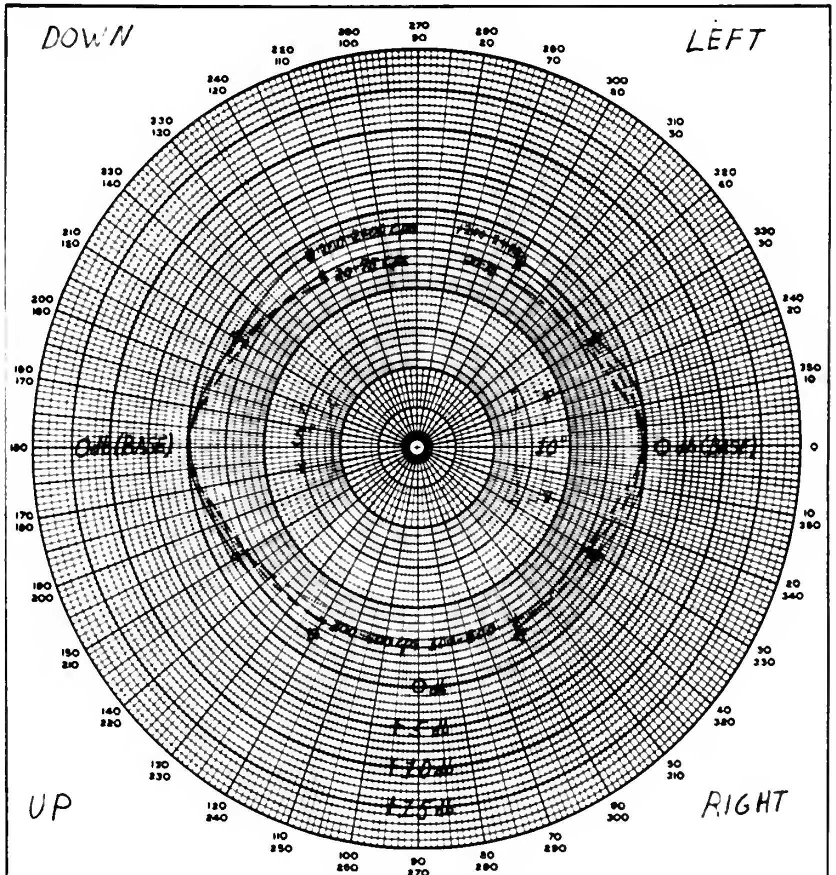


DIRECTIVITY PATTERN

CIRCULAR OPENING

Q = 624 FT³/min   RADIUS 2FT

FIGURE XVIII

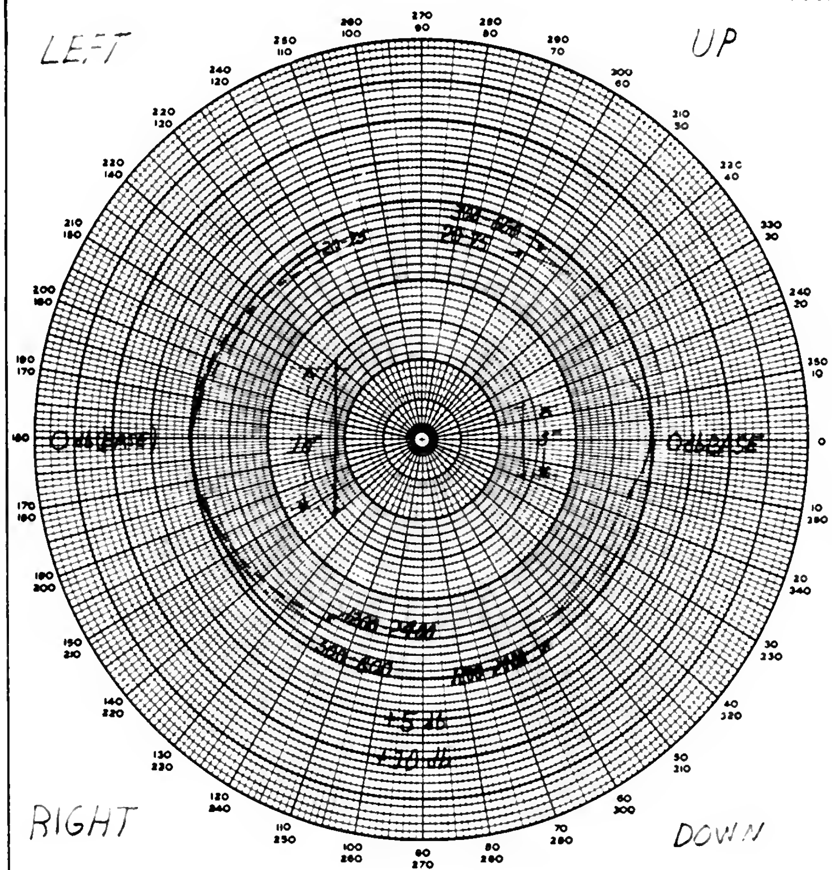


RECTANGULAR OPENING
DIRECTIVITY PATTERN

Q = 624 FT³/min

RADIUS 2ft

FIGURE XIX

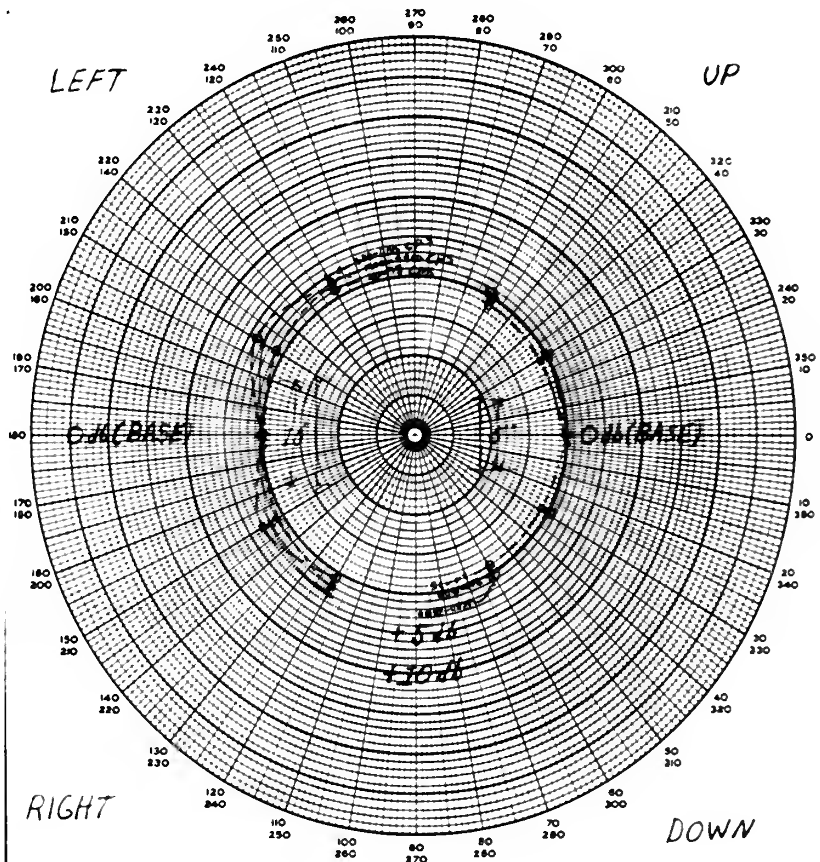


DIRECTIVITY PATTERN

DV STRAIGHT THROW

Q 624 FT³/min RADIUS 2 FT

FIGURE XX

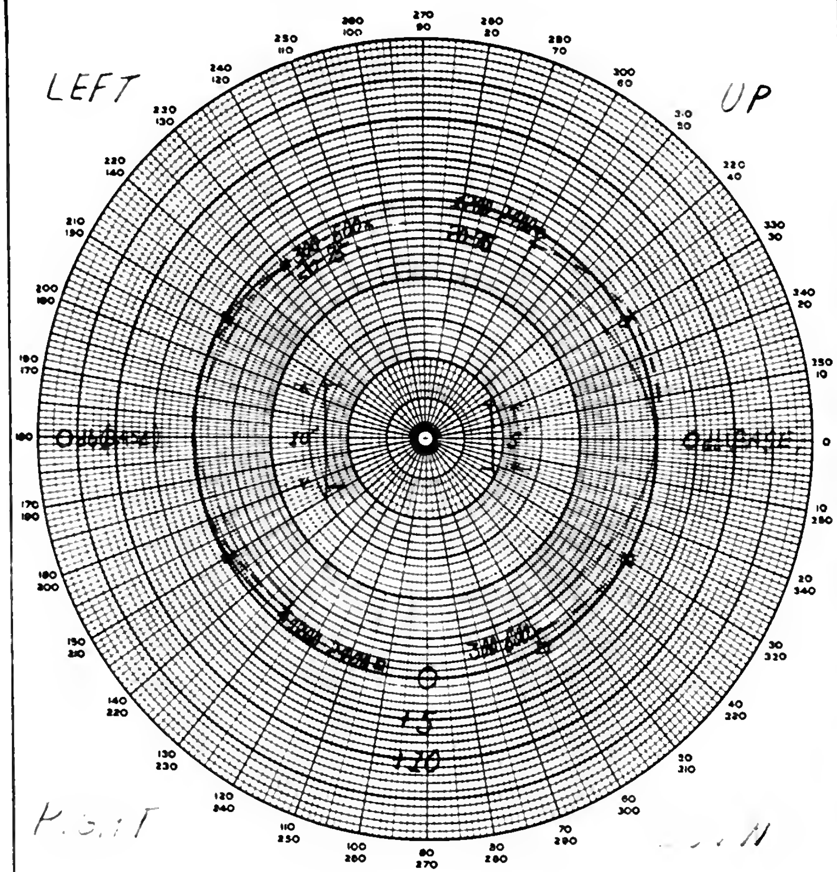


DIRECTIVITY PATTERN

DV DIVERGENT THROW

Q 624 FT³/min RADIUS 2 FT

FIGURE XXI

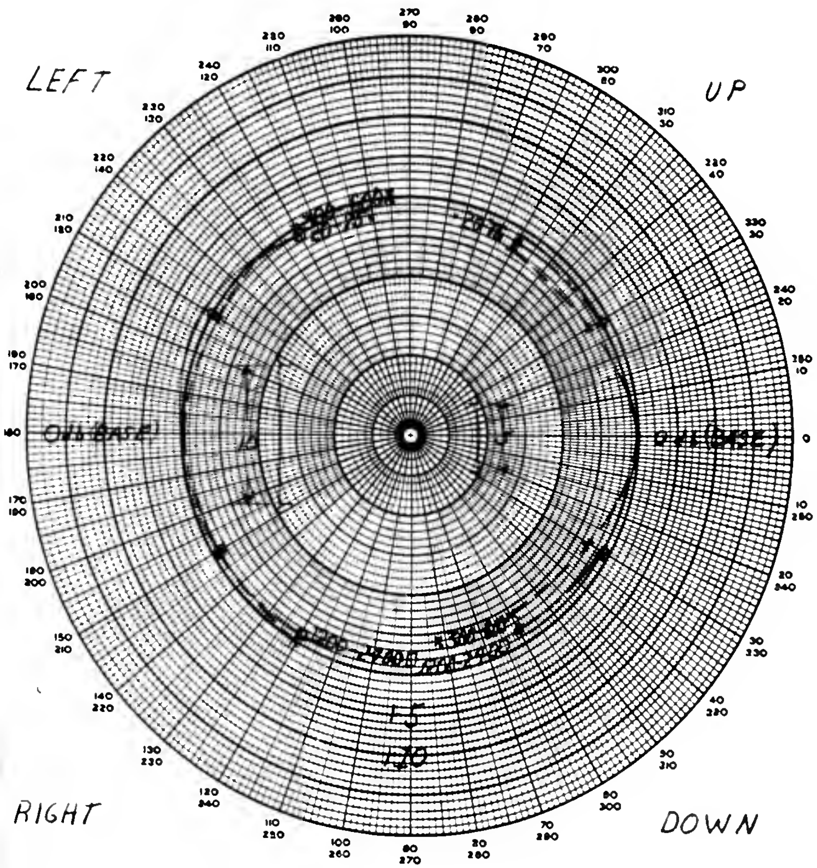


DIRECTIVITY PATTERN

TROV FULL OPEN DAMPER
STRAIGHT THROW

Q - 624 FT^3/min RADIUS 2 FT

FIGURE XXII

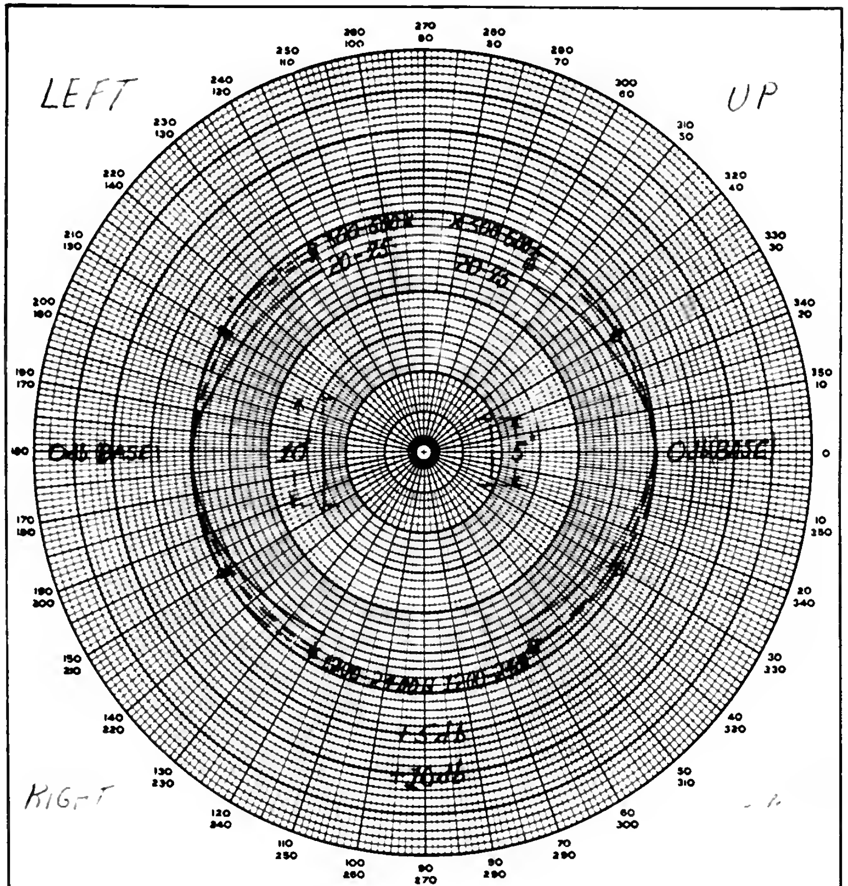


DIRECTIVITY PATTERN

TROV ½ DAMPER DIVERGENT
THROW

Q 624 FT^3/min RADIUS 2 FT

FIGURE XXIII

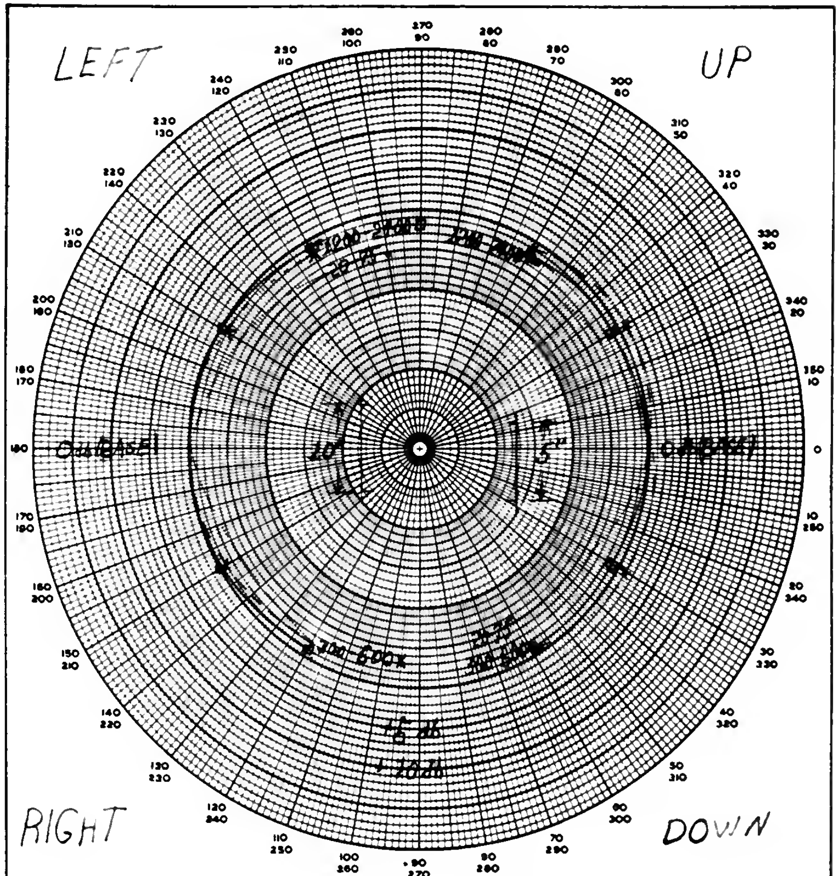


DIRECTIVITY PATTERN

TROV ½ DAMPER ST

Q 624 FT³

FIGURE XXIV

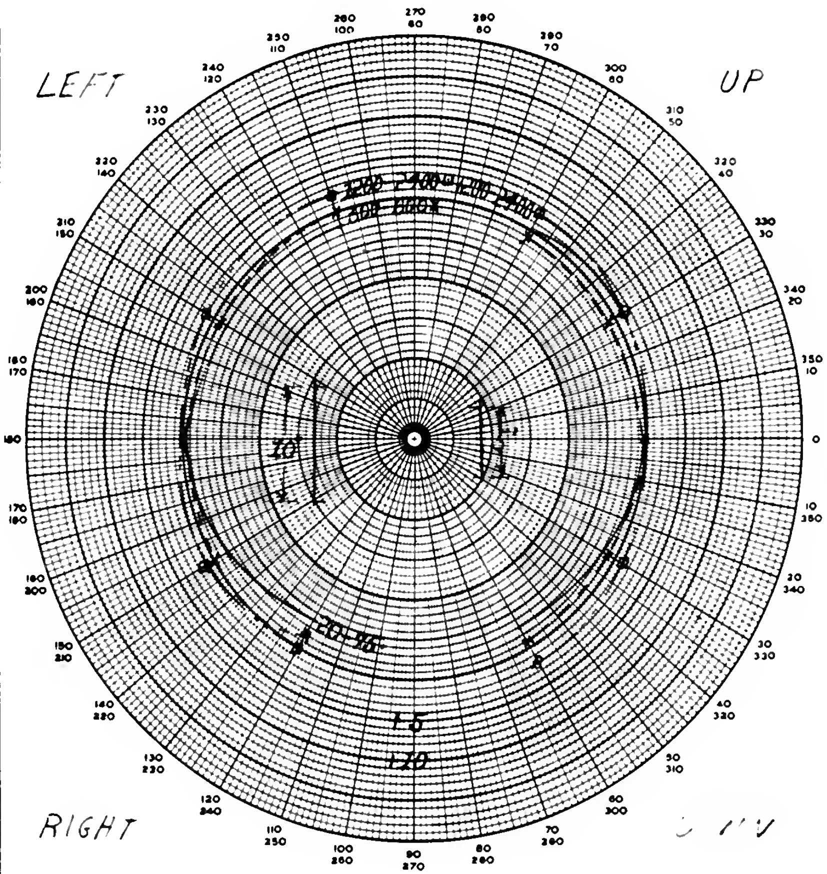


DIRECTIVITY PATTERN

TROV ⅓ DAMPER STRAIGHT THROW

Q = 624 FT³/min RADIUS 2 FT

FIGURE XXV

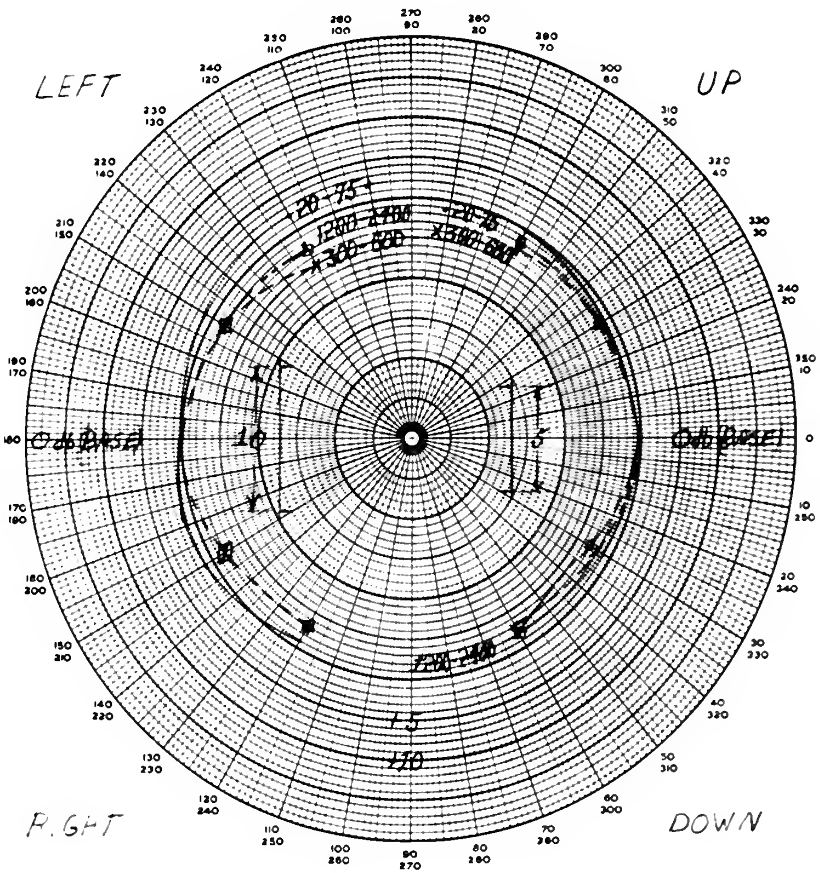


DIRECTIVITY PATTERN

TROV ⅓ DAMPER DIVERGENT THROW

$Q = 624\ FT^3/min$ RADIUS 2FT.

FIGURE XXVI

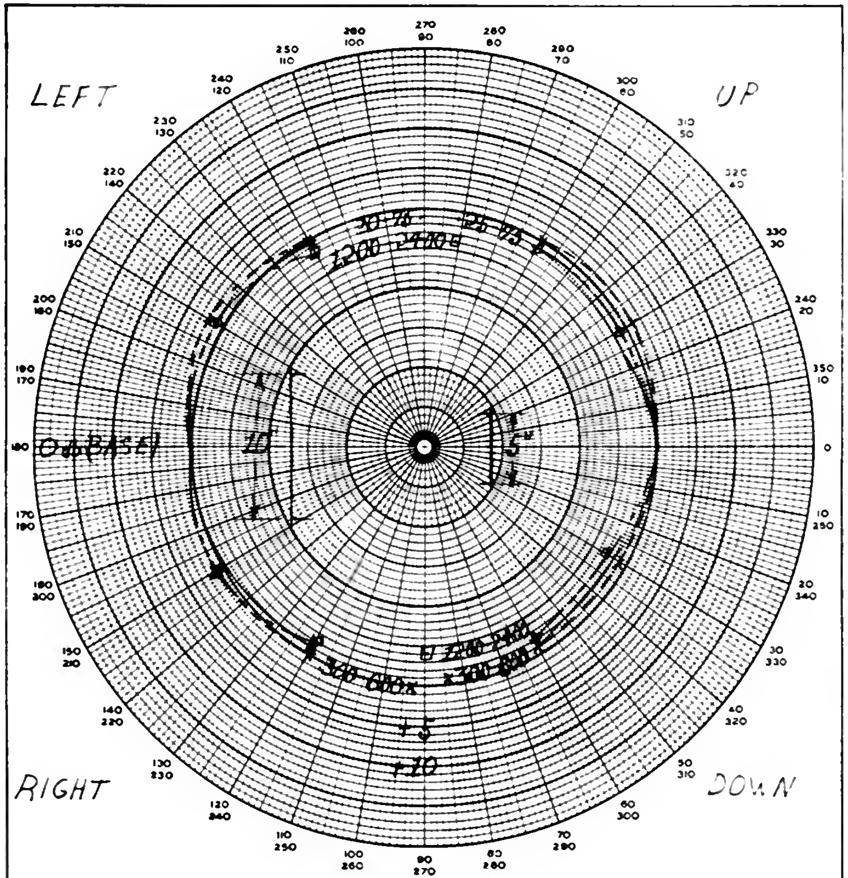


DIRECTIVITY PATTERN

DSV ⅓ DAMPER STRAIGHT THROW

Q, $624\ FT^3/min$ RADIUS 2FT

FIGURE XXVII

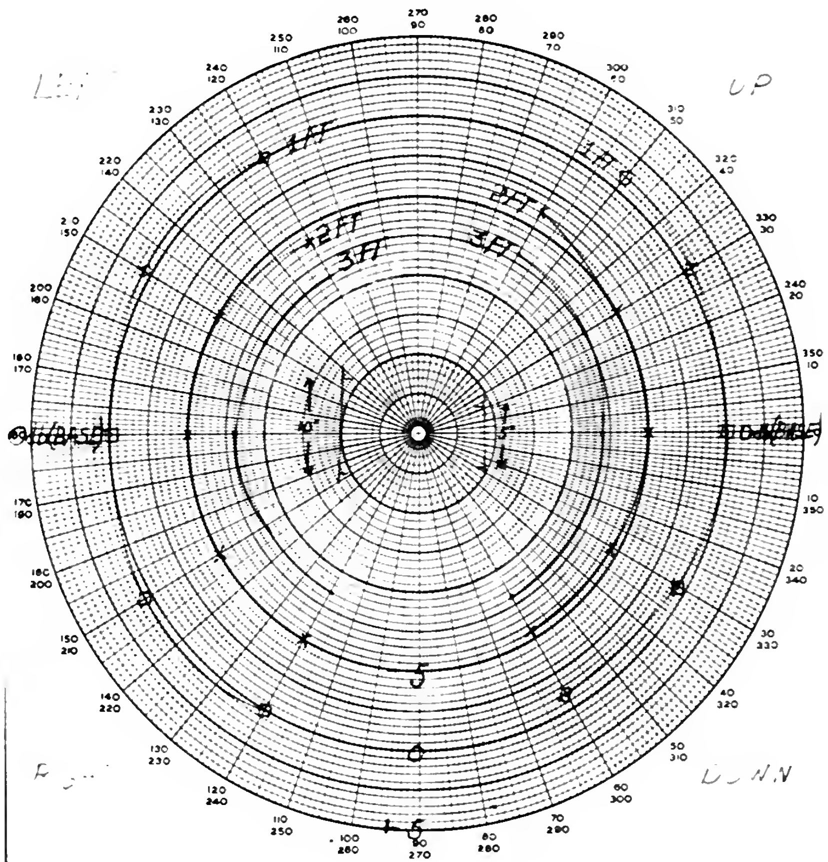


DIRECTIVITY PATTERN

DO GRILLE

Q 624 FT^3/min RADIUS 2 FT

FIGURE XXVIII

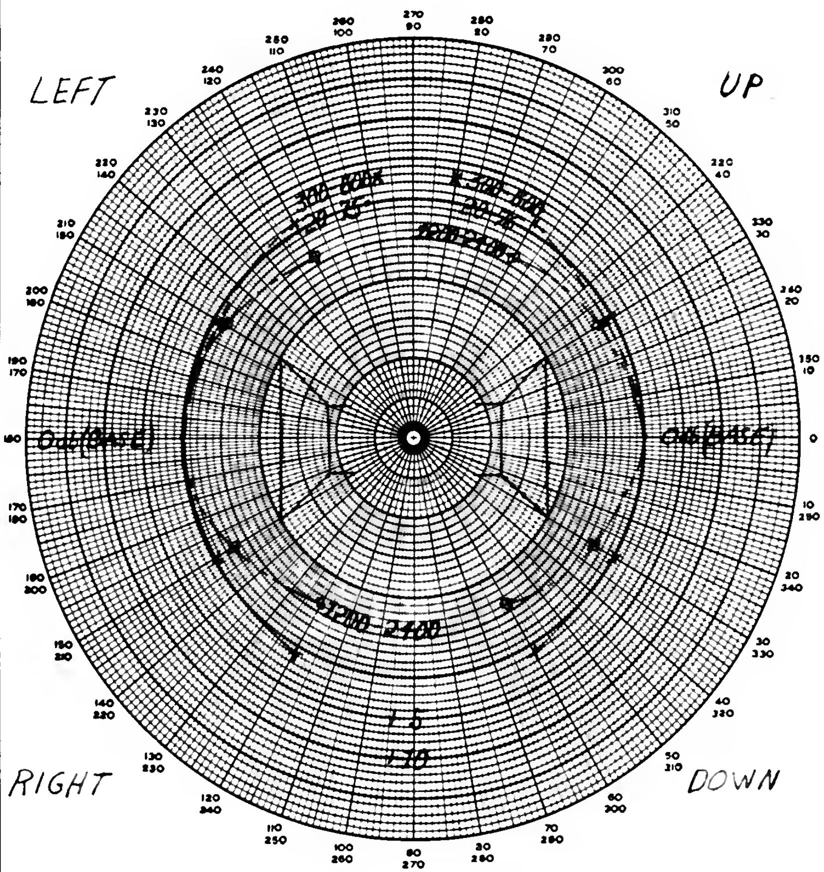


DIRECTIVITY PATTERN

DO GRILLE

RADIUS 1 FT; 2 FT AND 3 FT

FIGURE XXIX

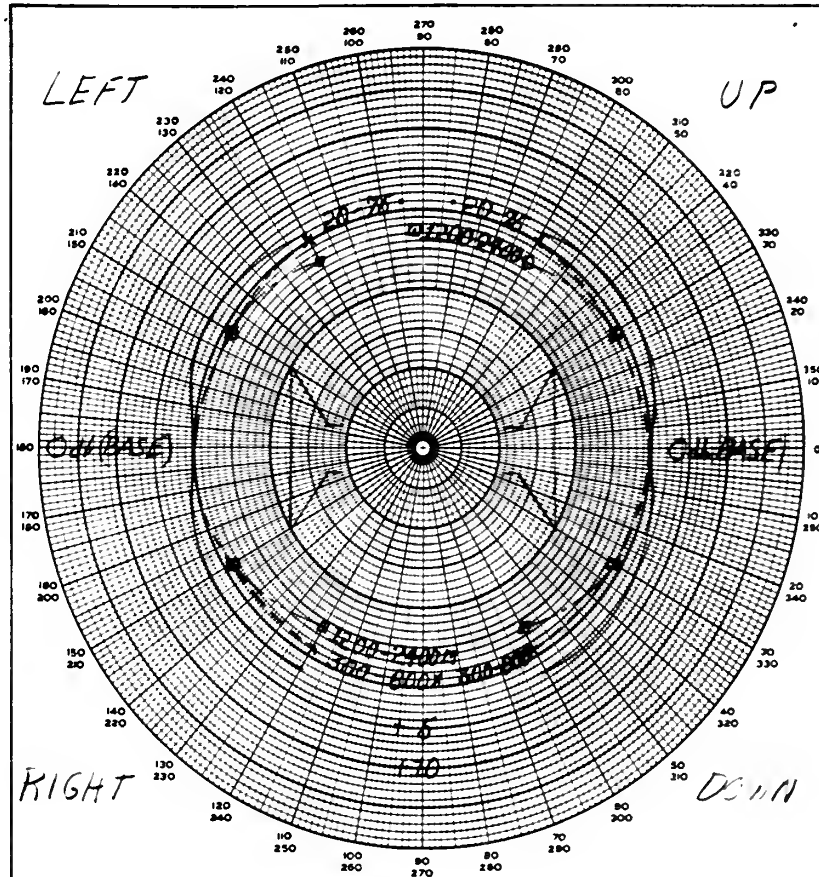


DIRECTIVITY PATTERN

ANEMOSTAT C-2 SIZE 20
CONE FULL OUT POSITION

Q 624 FT³/min

FIGURE XXX



DIRECTIVITY PATTERN

ANEMOSTAT C-2 SIZE 20
CONE FULL IN POSITION

Q 624 FT³/min RADIUS 2 FT

FIGURE XXXI

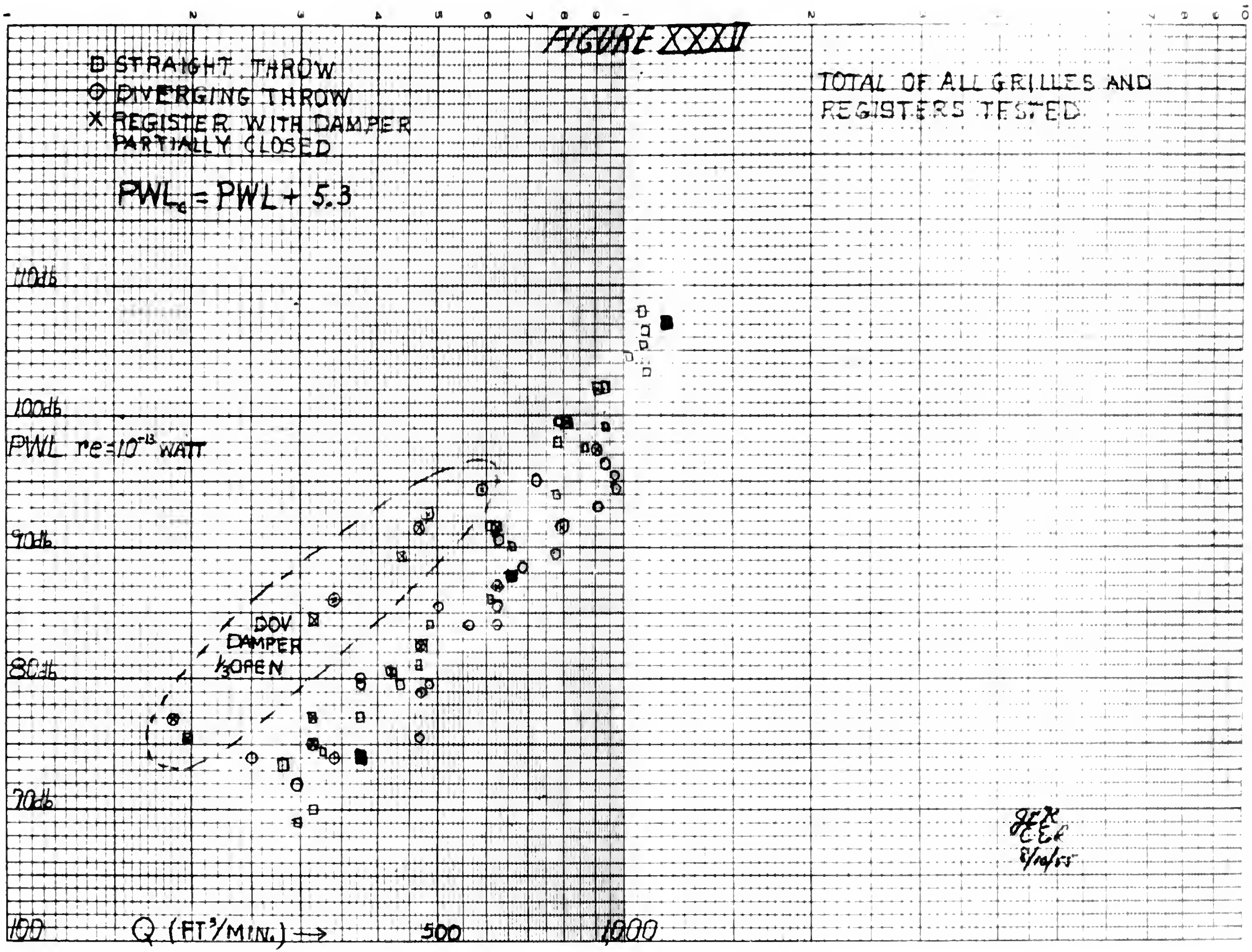


FIGURE XXXII
STRAIGHT THROW
DIVERGING THROW
REGISTER WITH DAMPER PARTIALLY CLOSED
PWL$_c$ = PWL + 5.3
TOTAL OF ALL GRILLES AND REGISTERS TESTED
110db
100db
PWL re=10^{-13} WATT
90db
80db
70db
DOV DAMPER 1/3 OPEN
100
500
1000
Q (FT³/MIN.) →

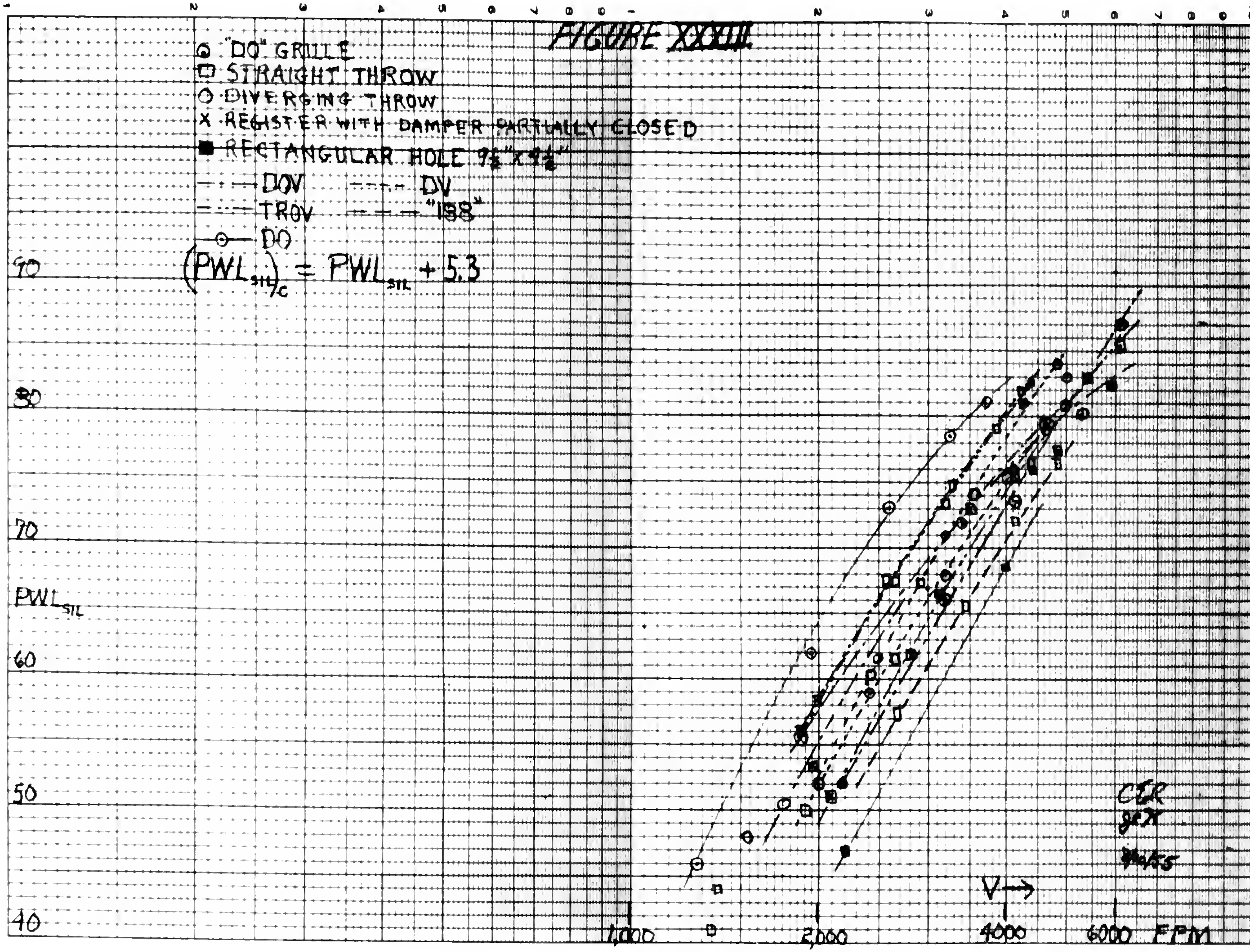


FIGURE XXXIII
"DO" GRILLE
STRAIGHT THROW
DIVERGING THROW
X REGISTER WITH DAMPER PARTIALLY CLOSED
RECTANGULAR HOLE 9½" x 9½"
DOV
DV
TROV
"138"
DO
$(PWL_{SIL})_C = PWL_{SIL} + 5.3$
PWL_SIL
90
80
70
60
50
40
V →
1,000
2,000
4000
6000 FPM
CER

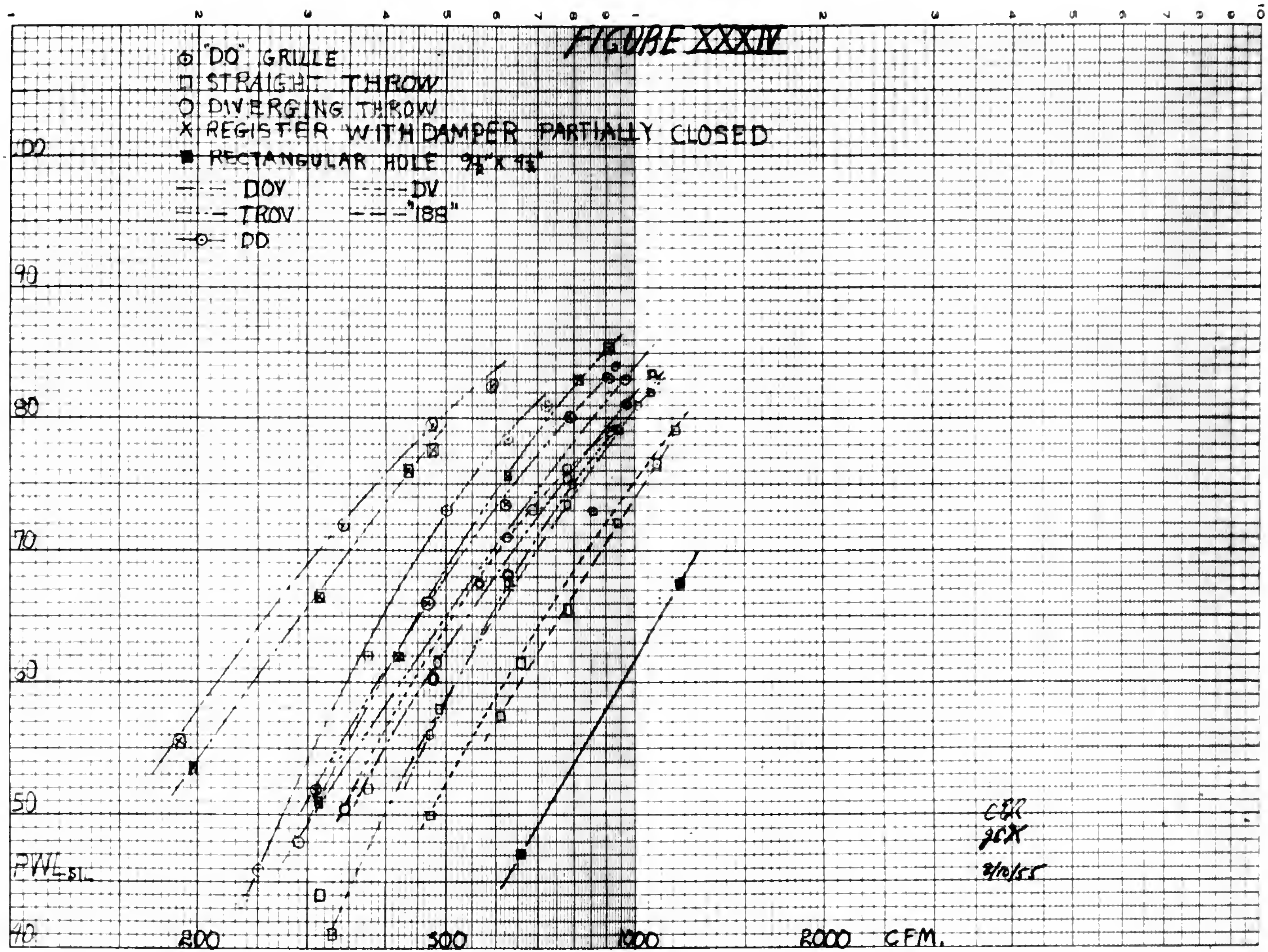


FIGURE XXXIV
"DO" GRILLE
STRAIGHT THROW
DIVERGING THROW
X REGISTER WITH DAMPER PARTIALLY CLOSED
RECTANGULAR HOLE 9½" X 4½"
DOV
DV
TROV
"188"
DD
100
90
80
70
60
50
40
PWL-51
200
500
1000
2000
CFM.
CER
3/10/55

FIGURE XXXV

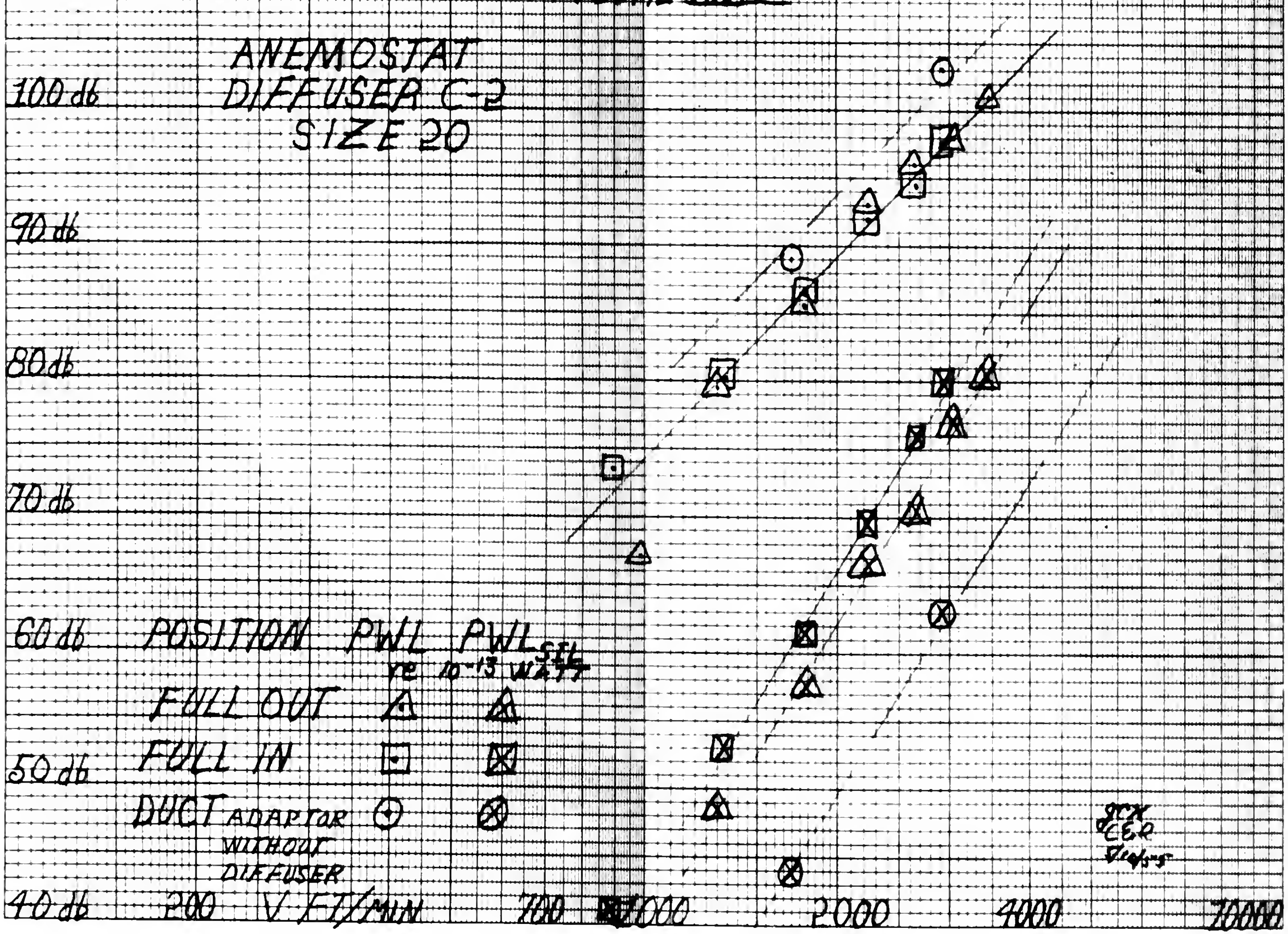

ANEMOSTAT
DIFFUSER C-2
SIZE 20
100 db
90 db
80 db
70 db
60 db
50 db
40 db
POSITION PWL PWL SEL
RE 10^{-13} WATT
FULL OUT
FULL IN
DUCT ADAPTOR WITHOUT DIFFUSER
200 V FT/MIN
700
1000
2000
4000
10000

FIGURE XXXVI

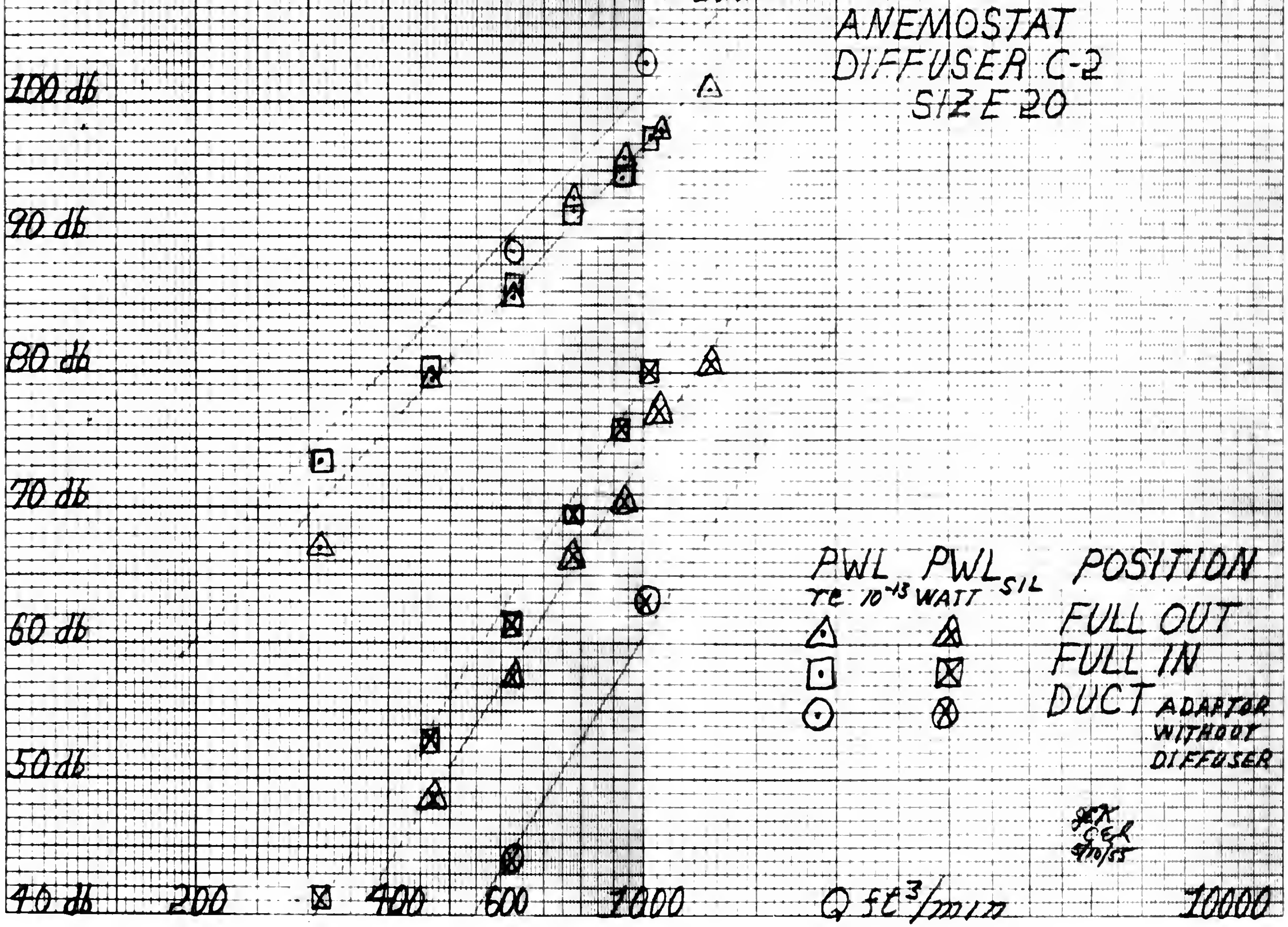
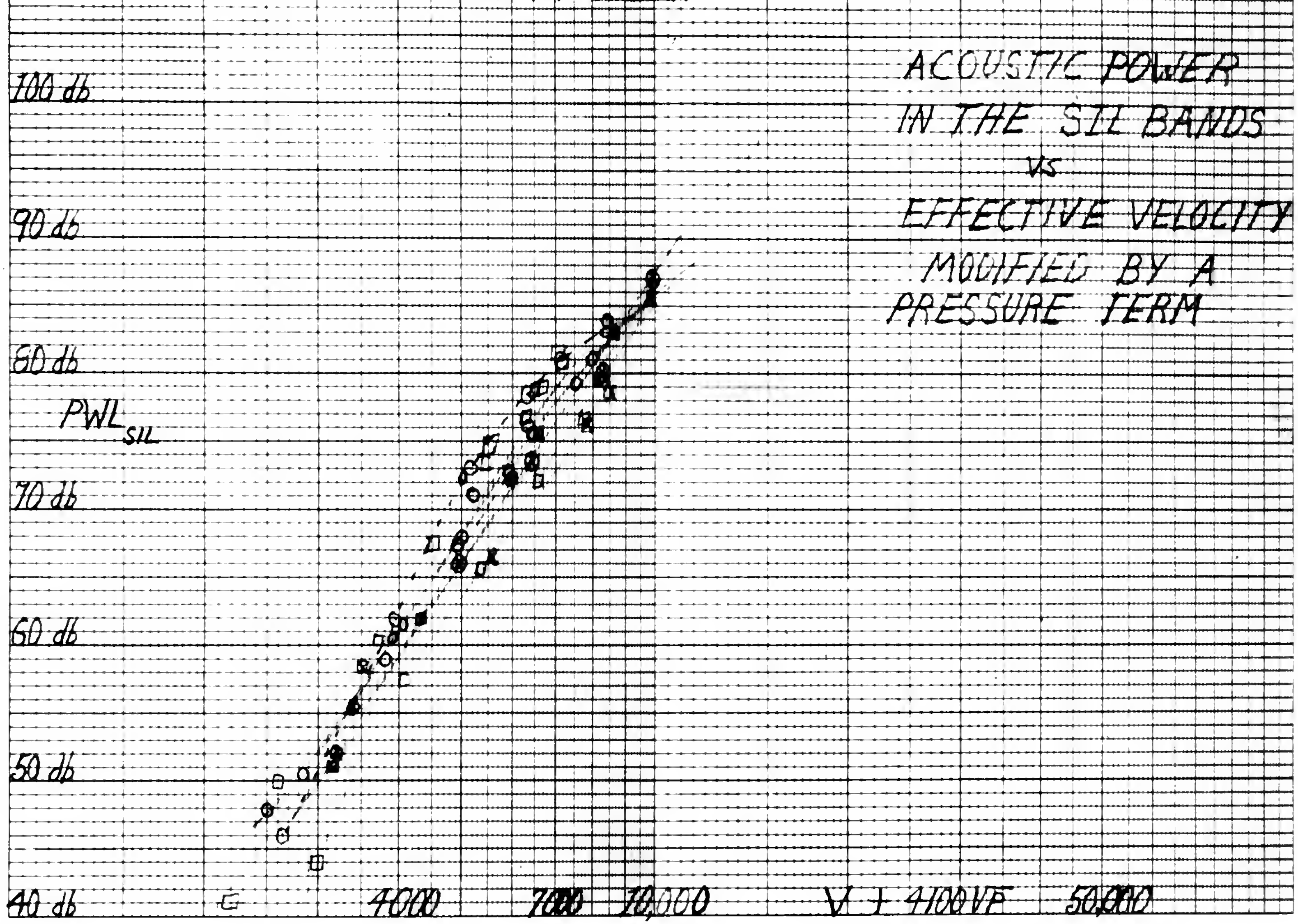


FIGURE XXXVII



VI DISCUSSION OF RESULTS

The various spectra curves show that the major portion of the acoustic power was contained in the lower bands of the frequency range investigated. (See Figs. III through XVIII.) The total acoustic power measured in the bands investigated varied approximately as the velocity to the sixth power.

As a function of volumetric rate of flow, the type of air throw had little effect upon the overall power level as long as the damper was not more than one-half closed. (See Fig. XXXII.) On the other hand, the shape of the spectrum was affected to a significant degree by the position of the dampers and the setting of the fins. The diverging throw and closing off of the dampers tended to accentuate the noise generated in the higher bands.

It is these higher bands that interest the designer most. In particular he is interested in the speech interference level bands. These are bands 12 through 20 for the particular one-third octave band filter being used.

To meet the needs of the designer the new quantity PWL_{SIL} was formulated. Its definition has previously been given in Chapter III. This quantity was found to vary widely with damper position and throw. (See Fig. XXXIV.) In this case the PWL_{SIL} for the open hole was less than the straight throw, which in turn was less than the diverging throw and so on to the register with damper in the one-third open position which

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had the highest value. This was to be expected; reduction of the effective area causes an increase in local velocities around the frets, fins or dampers. Theory (6) shows that the total power radiated is proportional to velocity to some power greater than one and is six in the particular case of the noise radiated by air flow past a cylindrical rod.

It would be desirable from the viewpoint of the designer to reduce all curves of PWL_{SIL} to a single curve or narrow band which could readily be expressed as some function of velocity, area, power loss in the wake, or pressure drop across the device. Thus if some common parameter for all the grilles and registers tested could be found, then the designer would have to look at a single chart or equation rather than have a chart of curves for each grille and register in the catalog.

The first trial along these lines was to plot PWL_{SIL} versus effective velocity. This brought all but two curves within a range of 11 db.

In an effort to find a common parameter, various schemes were tried. The ratio of the acoustic power of the SIL bands to the product $Q \times p$ versus Q and versus V was plotted; the PWL_{SIL} versus $Q \times p$ was plotted but none of the above were as good as the PWL_{SIL} versus V.

One other scheme was tried and with some success. This was a plot of PWL_{SIL} versus $(V + a\sqrt{p})$, where "a" is a constant to be determined. (See Fig. XXXVII.) It was believed that the acoustic power in the speech interference ranges might be a function of both the effective velocity and the pressure drop across the device. The square root of

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pressure was used since dynamic pressure is related to the square of velocity. There are two methods of selecting a value of "a": the first is to examine the curves and make an estimate of the value needed to obtain bunching of the curves, and the second, a more scientific method of determining "a", is to let "p" represent the dynamic pressure of a velocity "V_d".

$$p = \frac{1 V_d^2}{a^2}$$

where $1/a^2 = 1/2\rho$ if ρ = the density of the air.

In this investigation pressure was measured in inches of water and velocity in feet per minute; therefore, the value of "a" must also absorb the constants of conversion. This gave a value for "a" of 4100.

A plot was made of PWL_{SIL} versus $(V + a\sqrt{p})$ letting a = 4100 and it was found that the spread of the curves was considerably reduced, the spread being only about 2 db in the lower and upper region with about a 9 db spread in the center region. The upper and lower region are thus comparable to the error in the reading of the instruments on which the data were taken.

It must be emphasized that these curves are based on a single size of grille. Some other parameter must be used in order to extrapolate these results to different sizes.

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It must be emphasized that these curves are based on a single size of grille. Some other parameter must be used in order to extrapolate these results to different sizes.

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VII CONCLUSIONS

1. The total acoustic power in the frequency range investigated varied as the sixth power of the air velocity.

2. The acoustic power in the speech interference level varied between the 7.5th to 8.0th power of velocity.

3. The acoustic power in the SIL frequencies generated by grilles and registers of the same size can be related by means of the parameter $(V + a\sqrt{p})$ where "V" is the effective velocity, "p" is the pressure drop across the grille, and "a" is a constant which relates dynamic pressure to velocity.

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VIII RECOMMENDATIONS

It is recommended that grilles and registers of several different geometrical sizes and shapes be tested with the same apparatus as was used for this investigation. This should be done to determine whether the characteristic rise in noise that was found at the thirteenth octave band might be associated with the geometrical dimensions of the terminal opening rather than the characteristics of the grille itself. It is noted that the wave length of the thirteenth center band frequency is approximately equal to the long dimension of the adapter terminal opening. The fact that the rise is noted only in cases involving restricted flow would tend to substantiate this possibility.

The strong correlation that was found between the acoustic power in the speech interference bands and the effective velocity modified by $4100\sqrt{p}$ should be checked and substantiated by further tests and data.

The frequency characteristics in most cases indicate that the low frequency acoustical power output is governed by a different parameter than is the high frequency output. A further study should be made with the objective of finding these parameters.

The results of this investigation show that the noise power in the speech interference varies approximately as the eighth power of the velocity. The fact that noise generated from turbulence alone varies as the eighth power of the velocity would indicate that the acoustic power being generated in the SIL bands is due mainly to turbulence. The lower

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frequency response indicates a sixth power variation, but since it was not feasible to measure the acoustic power at the extremely low frequencies there are two possible explanation for this result. One is that all the power being generated at the low ranges was not measured because of instrumentation limitations. The other is that since the noise associated with flow past bodies varies as the sixth power of the velocity (6) the predominate noise is generated by the flow past the fins rather than by pure turbulence. A complete investigation of the low frequency response should be made with the objective of finding whether either of the two possibilities is correct.

A more complete and thorough investigation of directivity than was possible in this investigation should be made.

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APPENDICES

APPENDIX A. INSTRUMENT LIST

1. Hastings Air Meter, Thermocouple Type, Low Velocity Air Meter

2. Altec-Lansing 21-BR-200 microphone, serial no. 4892

3. Altec-Lansing power supply unit, type P-525-A

4. Edison Gauge: Edison Inclined Draft Company, Chicago

5. Magnecorder, type PT6-J

6. General Radio SPL Meter, type 1551-A, modified for cathode follower input

7. General Radio SPL Meter, type 1551-A

8. Telefon Fabrik Automatic A/S and Kobenhaven Filter (1/3 Octave Band) No. 11203-4

9. General Radio Calibrator, type 1307-A

10. General Radio Octave Band Analyzer, type 1550-A

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9. General Radio Calibrator, type 1307-A

10. General Radio Octave Band Analyser, type 1550-A

APPENDIX B. DATA

Calibration Data

a. Systems

The system was calibrated with a General Radio type B07-A calibrator by applying a 400 cycle per second tone of 100 db re = 0.0002 dynes/cm^2 at the condenser microphone. All other component calibration is relative to 400 cps. Frequent checks of calibration were made during the period of taking data to insure that excessive drift had not resulted.

b. Amplifier Response

Amplifier response is flat to within less than $\pm$ 1/2 db in the range of interest as is also the General Radio sound pressure level meter being used.

APPENDIX E. DATA

Calibration Data

a. Systems

The system was calibrated with a General Radio type 307-A calibrator by applying a 400 cycle per second tone of 100 db re = 0.0002 dynes/cm^2 at the condenser microphone. All other component calibration is relative to 400 cps. Frequent checks of calibration were made during the period of taking data to insure that excessive drift had not resulted.

b. Amplifier Response

Amplifier response is flat to within less than $\pm$ 1/2 db in the range of interest as is also the General Radio sound pressure level meter being used.

c. One-Third Octave Filter Calibration (10,000 tap)

Band Number	Band Center Frequency	Band Bounding Frequencies	Band Level Correction
1	50	45- 57	-4
2	63	57- 71	-3
3	80	71- 90	-2
4	100	90- 114	-2
5	125	114- 142	0
6	160	142- 180	0
7	200	180- 228	0
8	250	228- 284	0
9	320	284- 360	0
10	400	360- 456	0
11	500	456- 568	0
12	630	568- 720	0
13	800	720- 912	0
14	1000	912- 1136	0
15	1250	1136- 1440	0
16	1600	1440- 1824	0
17	2000	1824- 2272	0
18	2500	2272- 2880	0
19	3200	2880- 3648	0
20	4000	3648- 4544	0
21	5000	4544- 5760	0
22	6300	5760- 7296	-1
23	8000	7296- 9088	-1
24	10,000	9088-11520	-2

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1	50	45- 57	-4
2	63	57- 71	-3
3	80	71- 90	-2
4	100	90- 114	-2
5	125	114- 142	0
6	160	142- 180	0
7	200	180- 228	0
8	250	228- 284	0
9	320	284- 360	0
10	400	360- 456	0
11	500	456- 568	0
12	630	568- 720	0
13	800	720- 912	0
14	1000	912- 1136	0
15	1250	1136- 1440	0
16	1600	1440- 1824	0
17	2000	1824- 2272	0
18	2500	2272- 2880	0
19	3200	2880- 3648	0
20	4000	3648- 4544	0
21	5000	4544- 5760	0
22	6300	5760- 7296	-1
23	8000	7296- 9088	-1
24	10,000	9088-11520	-2

d. Effect of Windscreen on Sensitivity of Microphone

Band Number	Band Center Frequency	Band Level Correction
1	50	0
2	63	0
3	80	0
4	100	0
5	125	0
6	160	0
7	200	0
8	250	0
9	320	0
10	400	0
11	500	0
12	630	0
13	800	0
14	1000	0
15	1250	0
16	1600	-0
17	2000	-1
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5	125	0
6	160	0
7	200	0
8	250	0
9	320	0
10	400	0
11	500	0
12	630	0
13	800	0
14	1000	0
15	1250	0
16	1600	-0
17	2000	-1
18	2500	-2
19	3200	-3
20	4000	-2
21	5000	-3
22	6300	-5
23	8000	-2
24	10,000	-4

e. Microphone Calibration (grazing incidence)

Band Number	Band Center Frequency	Band Level Correction
1	50	0
2	63	0
3	80	0
4	100	0
5	125	0
.6	160	0
7	200	0
8	250	0
9	320	0
10	400	0
11	500	0
12	630	0
13	800	0
14	1000	0
15	1250	0
16	1600	0
17	2000	0
18	2500	-1
19	3200	-1
20	4000	-1
21	5000	-1
22	6300	0
23	8000	0
24	10,000	0

f. Self Noise Generated by Windscreen. See Fig. A-1.

g. Calibration of Air-Meter. See Fig. A-2.

e. Microphone Calibration (grazing incidence)

Band Number	Band Center Frequency	Band Level Correction
1	50	0
2	63	0
3	80	0
4	100	0
5	125	0
6	160	0
7	200	0
8	250	0
9	320	0
10	400	0
11	500	0
12	630	0
13	800	0
14	1000	0
15	1250	0
16	1600	0
17	2000	0
18	2500	-1
19	3200	-1
20	4000	-1
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f. Self Noise Generated by Windscreen. See Fig. A-1.

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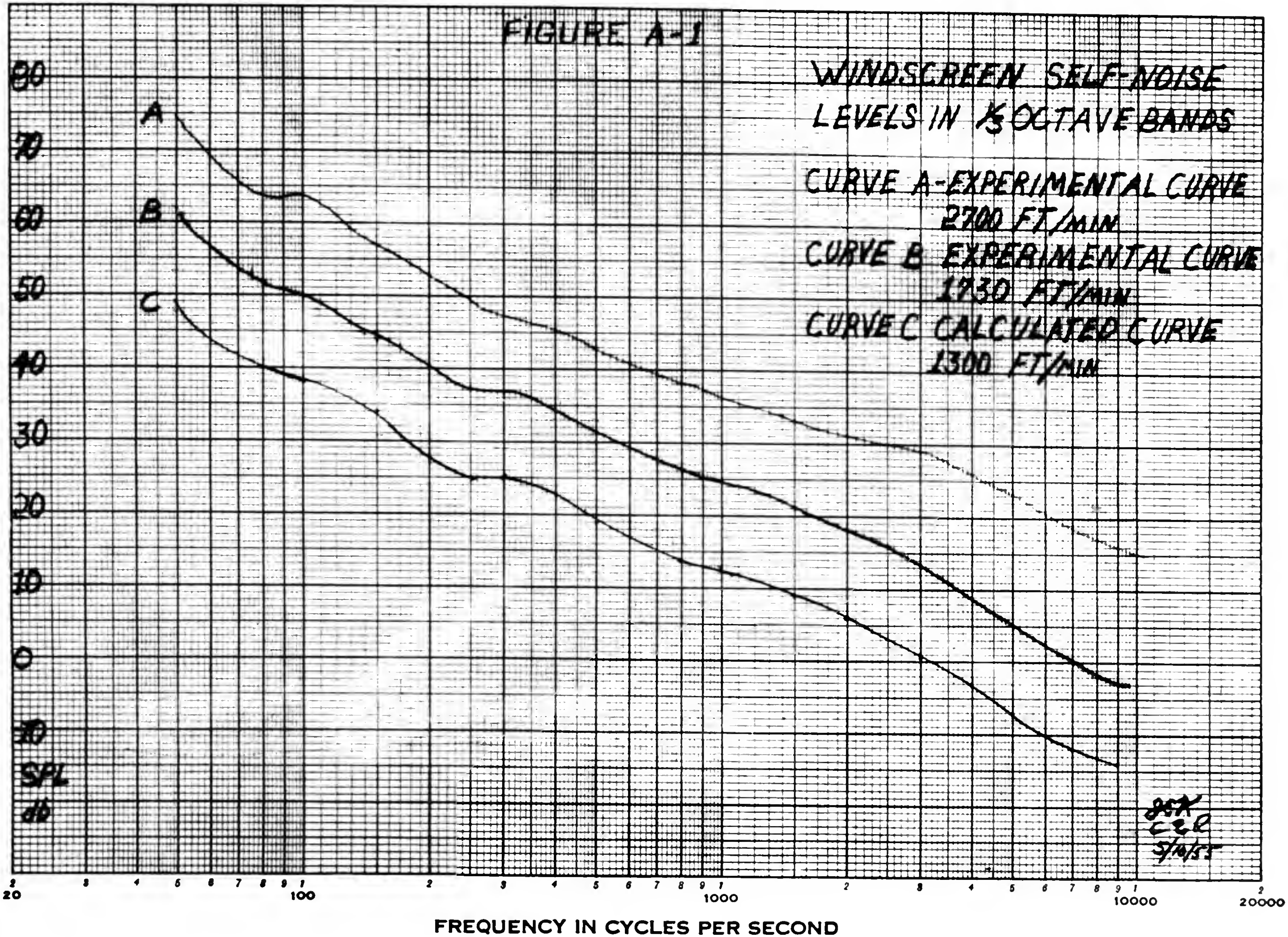
FIGURE A-1
WINDSCREEN SELF-NOISE
LEVELS IN 1/3 OCTAVE BANDS
CURVE A-EXPERIMENTAL CURVE
2700 FT/MIN
CURVE B EXPERIMENTAL CURVE
1730 FT/MIN
CURVE C CALCULATED CURVE
1300 FT/MIN
A
B
C
80
70
60
50
40
30
20
10
0
-10
SPL
db
20
100
1000
10000
20000
FREQUENCY IN CYCLES PER SECOND

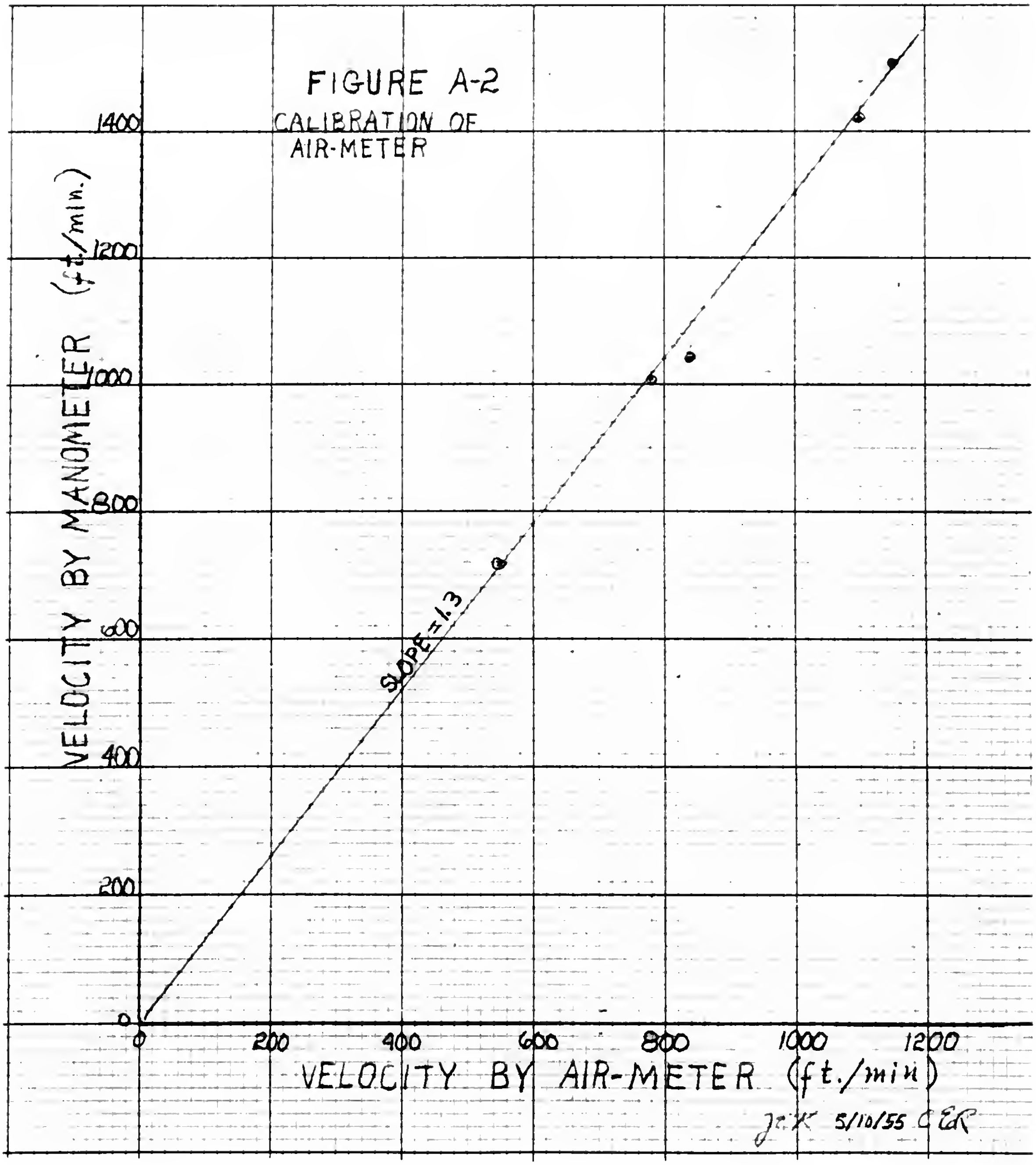
FIGURE A-2
CALIBRATION OF
AIR-METER
VELOCITY BY MANOMETER (ft./min.)
1400
1200
1000
800
600
400
200
0
SLOPE = 1.3
0
200
400
600
800
1000
1200
VELOCITY BY AIR-METER (ft./min)
5/10/55

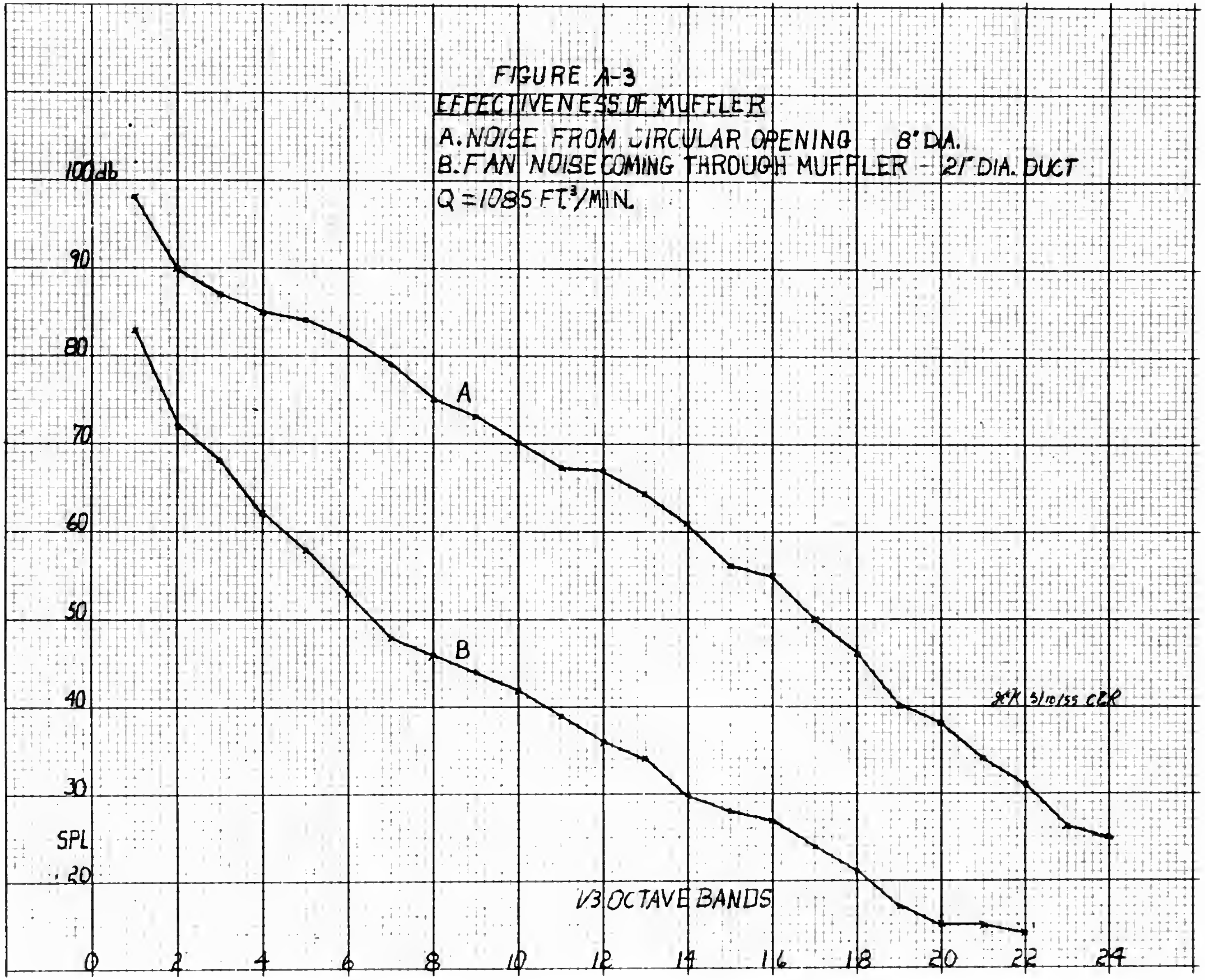
FIGURE A-3
EFFECTIVENESS OF MUFFLER
A. NOISE FROM CIRCULAR OPENING 8' DIA.
B. FAN NOISE COMING THROUGH MUFFLER - 21" DIA. DUCT
Q = 1085 FT³/MIN.
100db
90
80
70
60
50
40
30
SPL
20
A
B
1/3 OCTAVE BANDS
0
2
4
6
8
10
12
14
16
18
20
22
24

h. **Effectiveness of Sinusoidal Muffler in Isolating Fan Noise from Test Section.** See Fig. A-3.

APPENDIX C. CALCULATIONS

a. PWL

The PWL proceeding down the measuring duct to the exponential horn is given approximately by

$$PWL = SPL + 10 \log_{10} S$$

where the definitions of the symbols are as given in Chapter III. This expression assumes normal atmospheric conditions of temperature and pressure and that the sound pressure level is uniform across the duct. The area of the duct at the point of SPL measurement was 2.4 ft^2. Therefore,

$$PWL = SPL + 10 \log_{10} 2.4$$

b. Calculation of PWL_{SIL}

$$PWL_{SIL} = SIL_{(2.4\ ft^2)} + 10 \log_{10} S$$

where S is the area in square feet over which the given SIL exists. The value of S at this point was 2.4 ft^2. Therefore:

$$PWL_{SIL} = SIL_{(2.4\ ft^2)} + 10 \log\ 2.4$$

c. Calculation of Q

$$Q = V_1 A_1$$

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$$PWL_{SIL} = SIL_{(2.4\ ft^2)} + 10 \log 2.4$$

c. Calculation of Q

$$Q = V_1 A_1$$

where V_1 and A_1 are the average velocity and area respectively in the air measurement section. Since $A_1 = 2.4\ ft^2$ at measurement section then

$$Q = V_1 \times 2.4$$

$$Q(c\ fm) = 2.4\ V_1(f\ pm)$$

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$$Q(c\,fm) = 2.4\ V_1(f\,pm)$$

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2. L. L. Beranek, G. W. Kamperman, and C. H. Allen, "Noise of Centrifugal Fans." Journal of the Acoustical Society of America, 27, 217-219 (1955).

3. L. L. Beranek, Acoustics. (McGraw-Hill Book Co., N. Y., 1954).

4. R. H. Bolt, S. J. Lukasik, A. W. Nolle, and A. D. Frost, Handbook of Acoustic Noise Control, Vol. I. WADC Technical Report 52-204, December 1952.

5. Bureau of Ships Notice 9380, ser. 549-1351, 1 July 1954.

6. I. Dyer, General Electric Industrial Acoustics Course III Lecture Notes, Part II: Aerodynamic Noise. General Electric report number R 556 L102, March 25, 1955.

7. Heating Ventilating Air Conditioning Guide 1953. Chapter 41, "Sound Control." The American Society of Heating and Ventilating Engineers, New York, N. Y.

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